Options for measuring, preventing, and mitigating impacts due to improvements to the Sacramento and San Joaquin flood control projects

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DAVID FORD CONSULTING ENGINEERS

David Ford Consulting Engineers Inc.
PO Box 188529
Sacramento, CA 95818
2015 J Street, Suite 200
Sacramento, CA 95814
Ph. 916.447.8779
Fx. 916.447.8780

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Executive summary

Situation

The Central Valley flood control system, which includes the Sacramento River Flood Control Project (SRFCP) and the Lower San Joaquin River and Tributaries Project (LSJRTP), protects more than 500,000 people and their property (Harder 2006). With the State of California Reclamation Board (Board) acting as non-federal sponsor, the federally authorized system of levees, weirs, and bypass channels was funded by a 1/3–2/3 federal-local cost sharing agreement. Congress authorized the SRFCP in 1917; construction began in 1918 and continued through the 1950s. The LSJRTP was authorized in 1944, and construction began in 1956. The State of California agreed to operate, maintain, replace, and repair system components upon completion of construction.

Subsequent to authorization of the SRFCP and LSJRTP, additional levees, bypasses, and multipurpose dams with flood-control storage were constructed. These projects were the result of private developments, the federal Central Valley Project, the State Water Project, and other federal flood management activities in the San Joaquin Valley. These later projects are integrated with the SRFCP and LSJRTP, which remain central components of the Central Valley flood control system.

As a part of its agreement with the US Army Corps of Engineers (USACE) to maintain the SRFCP and the LSJRTP, the Board regulates encroachments on the system. When determining whether to issue or deny permits for such encroachments, the Board must analyze the degree to which the encroachments alter adversely the performance of the system.

Goals

The overall goal of this report is to provide information with which the Board and its staff can enhance decision making for permitting modifications to the flood control system.

Specific goals are:

- To identify measurement standards or indices that applicants and the Board and its staff can use to identify and evaluate impacts to the system that result from proposed modifications.
- To identify options that could be used to prevent or mitigate adverse impacts.

Tasks

Tasks that we completed to achieve these goals include:

- Researching existing documents to develop an understanding of the SRFCP and LSJRTP design. Chapter 2 of this report summarizes our findings.
- Describing potential improvements to the flood control system that could be proposed. Chapter 3 of this report includes this description.
- Proposing a set of indices that identify direct and indirect impacts of system improvements. These index options are described in Chapter 4 of this report.
- Identifying options that could be implemented to prevent or mitigate any adverse impact identified with the proposed indices. These prevention and mitigation options are presented in Chapter 5.
- Soliciting input from a group of California flood management experts and stakeholders who will be affected by use of the identified indices and prevention and mitigation options. Comments from these experts and stakeholders are included in Appendix V of this report.

Findings

Possible improvements to the system include flood management or flood control measures that

- Decrease the flow rate for a selected exceedence probability.
- Decrease the river stage corresponding to a given flow rate.
- Decrease the floodplain stage corresponding to a given river stage.
- Reduce the damage incurred by water reaching a given floodplain stage.

The impact of proposed improvements to the system in any of these categories can be measured objectively with the indices shown in Table 1. These indices include physical, economic, and statistical measures of the impact.

The list of indices is intended to serve as a guideline only. Depending upon the situation at hand, an applicant and/or the Board may use one or some combination of indices. Other indices may be appropriate, as well, if the indices identified fail to distinguish impacts on unique features.

Computer applications are available to determine these indices. However, software in common use will require enhancements if it is to be used successfully and widely. Further, all the indices identified rely on simulation of flows throughout the system. If this simulation is to be done in a fair and equitable manner, a system-wide hydraulics model must be developed, disseminated, maintained, and used uniformly by Board staff and applicants.

If adverse impacts are identified, mitigation or prevention may be required. Table 2 shows options available.

Prevention and mitigation options presented include structural options that reduce or eliminate the impact by managing the waters and nonstructural options that manage the consequences of the impact without eliminating the impact. These options may be used alone or in combination. Again, depending upon the situation, other mitigation efforts may be appropriate.

Table 1. Indices of impacts

1. Change in water-surface elevation or flow conveyance for system design flow
2. Change in water-surface elevation for flow of specified annual exceedence probability
3. Change in potential damage for system design flow
4. Change in potential damage for flow of specified annual exceedence probability
5. Change in expected annual damage (EAD)
6. Change in portion of expected annual damage due to flows greater than system design flow
7. Change in annual probability of inundation of interior floodplain
8. Change in probability of passing safely design flow
9. Change in probability of passing safely flow of specified probability

Table 2. Prevention and mitigation options

1. Avoid the impact by disallowing the improvement.
2. Mitigate adverse impact with construction of structural measure(s).
3. Notify those who may suffer adverse impacts.
4. Reimburse those who suffer increased damage potential (single event or expected).
5. Insure those with increased damage potential.
6. Collect impact fee to offset increased construction cost for system-wide plan of flood control.
7. Pay the cost associated with any increased damage if and when it occurs.
8. Provide other types of insurance.

1 Purpose of this study

The Central Valley flood control system, which includes the Sacramento River Flood Control Project (SRFCP) and the Lower San Joaquin River and Tributaries Flood Control Project (LSJFCP), protects more than 500,000 people and their property (Harder, 2006). To accomplish this, the system relies on reservoirs, channels, bypasses, weirs, and levees.

Improvements or enhancements to certain system components can increase the level of protection provided by the projects, further reducing flood damage and risk to life and safety. For example, a levee protecting an urban area could be raised, or reservoir operation could be modified to make better use of new technology. However, the tight interconnectivity and integration of system components requires that such improvements be considered in a system-wide context. For example, changes to operation of a system reservoir will change flow rates far downstream—perhaps even in the Delta. And changes to a levee may alter water levels miles downstream.

The California State Reclamation Board (herein referred to as the Board) has responsibility for overseeing improvements to ensure that impacts are identified fairly and for controlling improvements to minimize the adverse effects. Specifically, Title 23 of the California Water Code provides that

[P]lacement, construction, reconstruction, removal, or abandonment of any landscaping, culvert, bridge, conduit, fence, projection, fill, embankment, building, structure, obstruction, encroachment or works of any kind, and including the planting, excavating, or removal of vegetation, and any repair or maintenance that involves cutting into the levee, wholly or in part within any area for which there is an adopted plan of flood control, must be approved by [the Reclamation] *board prior to commencement of work.*

The Water Code provides that the Board may deny a permit for work proposed if the work could:

(2) Obstruct, divert, redirect, or raise the surface level of design floods or flows, or the lesser flows for which protection is provided;

(3) Cause significant adverse changes in water velocity or flow regimen;

(7) Increase the damaging effects of flood flows; or

(8) Be injurious to, or interfere with, the successful execution, functioning, or operation of any adopted plan of flood control.

The Water Code, however, does not identify specific measurements or indices that the Board must use as the basis for these determinations, nor does the Code identify options for mitigating any adverse impacts. Accordingly, the Board directed this study of options and preparation of this report.

In the study report, we first describe the components of the Sacramento River Flood Control Project and the Lower San Joaquin River and Tributaries Project.

The basis for design of key components of these projects is critical to determination of indices of impact; we provide information on the design in Chapter 2.

We describe in Chapter 3 improvements to the system for which the Board and applicants must identify and evaluate impacts and, if necessary, propose prevention or mitigation measures.

In Chapter 4, we propose a set of indices, one or more of which can be used by the Board and by applicants to identify and measure impacts from proposed improvements to the flood control system.

Finally, in Chapter 5, we propose options that could prevent and mitigate unacceptable impacts.

We do not in this report offer recommendation regarding which index or which prevention or mitigation option should be used for any case. Such decisions are for the Board, its staff, and applicants to make. However, we do make certain recommendations regarding analysis procedures.

2 Flood control system overview

System features

The Central Valley flood control system includes the Sacramento River Flood Control Project (SRFCP) and Lower San Joaquin River and Tributaries Project (LSJRTP).

Congress authorized the SRFCP in 1917 as the first federal flood management work to be constructed outside the Mississippi River Valley. With the California Reclamation Board acting as non-federal sponsor to contribute 1/3 the cost, construction began in 1918 and continued through the 1950s. The SRFCP consists of a system of levees, weirs, and bypass channels. According to the US Army Corps of Engineers [USACE] (1999), specific facilities include:

- 1000 miles of levees
- 440 miles of river, canal, and stream channels
- 5 major weirs
- 2 sets of outfall gates
- 3 major drainage pumping plants
- 95 miles of bypasses comprising areas aggregating 100,000 acres
- 5 low-water check dams
- 50 miles of drainage canals and seepage ditches
- Numerous minor weirs and control structures, bridges, and gaging stations

Congress authorized the LSJRTP in 1944; it was the first major flood control project in the San Joaquin Valley. With the California Reclamation Board again acting as non-federal sponsor, construction of the LSJRTP began in 1956. Specific facilities include (USACE 1955a):

- 100 miles of levees
- New Hogan Dam on the Calaveras River
- New Melones Dam on the Stanislaus River
- Don Pedro Dam on the Tuolumne River
- Chowchilla and Eastside Bypasses

Subsequent to authorization of the SRFCP and LSJRTP, additional major levees, bypasses, and multipurpose dams with flood-control storage were constructed. These projects were the result of private developments, the federal Central Valley Project, the State Water Project, and several federal flood management projects in the San Joaquin Valley. These later projects are integrated with the SRFCP and LSJRTP, which remain central components of the Central Valley flood control system.

The Delta, lying between these two project areas, includes 60 islands and is protected by 1000 miles of non-project levees [California Department of Water Resources (DWR) 2005].

Figure 1 shows locations of current Central Valley levees maintained by reclamation districts, levee districts, drainage districts, and municipalities. Delta levees and 300 miles of levees maintained directly by DWR are not shown.

System design standard

For the SRFCP and LSJRTP, USACE project design flows define the intended capacity of the system. These flows were developed by USACE from review of the largest floods for which records were adequate for analysis. Project design flows for the system are shown in Figure 1.

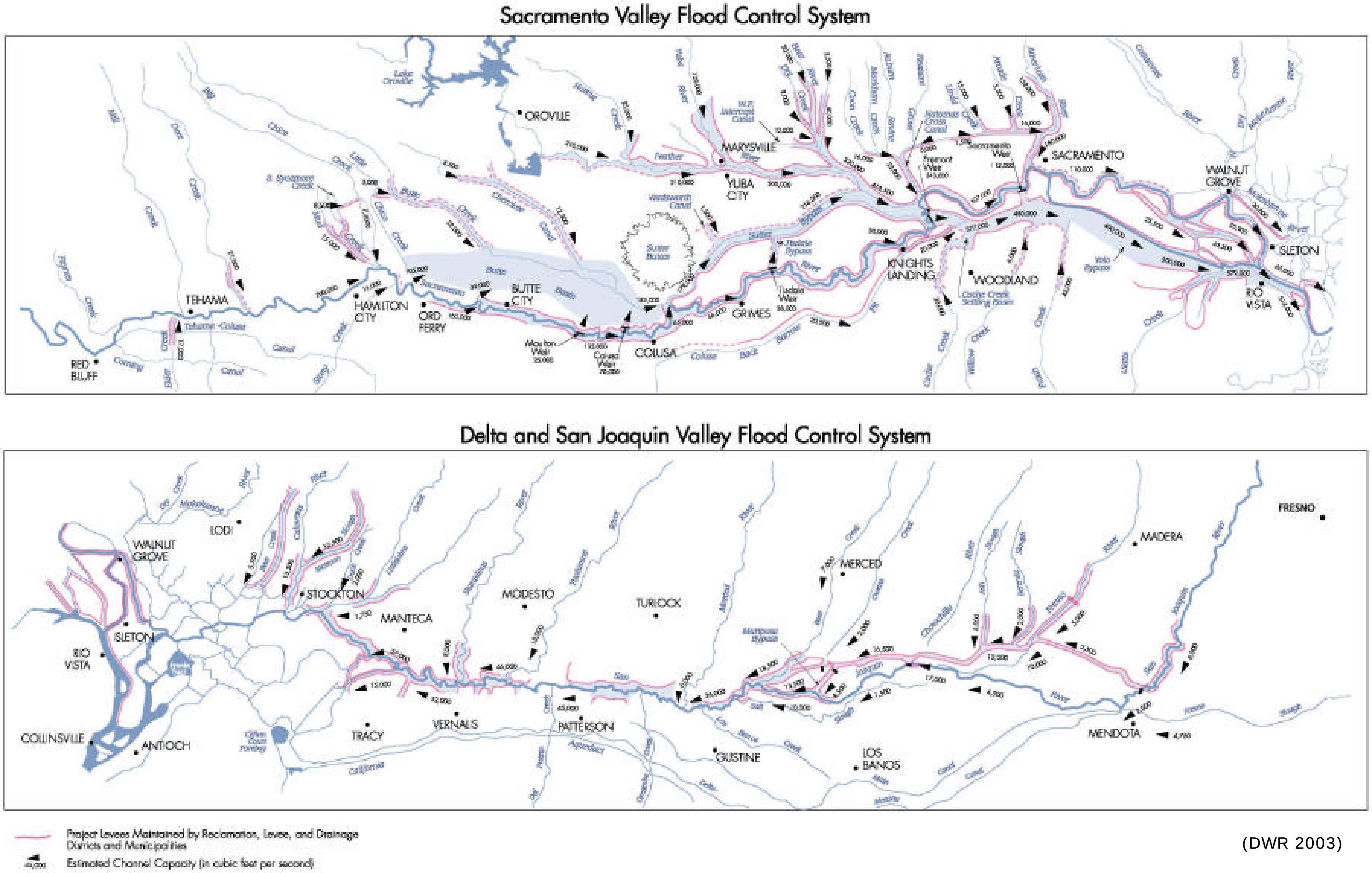
For the project design flows, the USACE also computed project design water surface profiles. The project minimum top of levee profile was then defined as the project design water surface profile. Freeboard was added to account for uncertainty in system analysis and performance.

For the SRFCP, the final project design water surface profiles and design flows are presented graphically on 4 sheets in *USACE Sacramento District file 50-10-3334*, dated March 15, 1957 (USACE 1957b). The water surface profiles shown on these sheets are referred to as the *1957 design water surface* or, more commonly, *the '57 profile*. For illustration, one of these sheets is reproduced here as Figure 2.

For the LSJRTP, the final design water surface profiles are provided in *USACE Sacramento District file SJ-20-60*, dated December 23, 1955. Project design flows are provided in an accompanying design memorandum (USACE 1955a).

Our review of original project design documents that are available identified the following design steps:

1. Significant flood events of record were identified and evaluated for inclusion in hydrologic computations. The largest flood events for which sufficient data were available were selected for further analysis. As major flood events occurred during the design and construction, data from those events were added, and the design was re-evaluated. This re-evaluation is critical, as the design and construction occurred over many years.
2. For each flood event in the set, unimpaired (unregulated) flows at the upstream end of the project were estimated.



(DWR 2003)

Figure 1. System levees and design flows

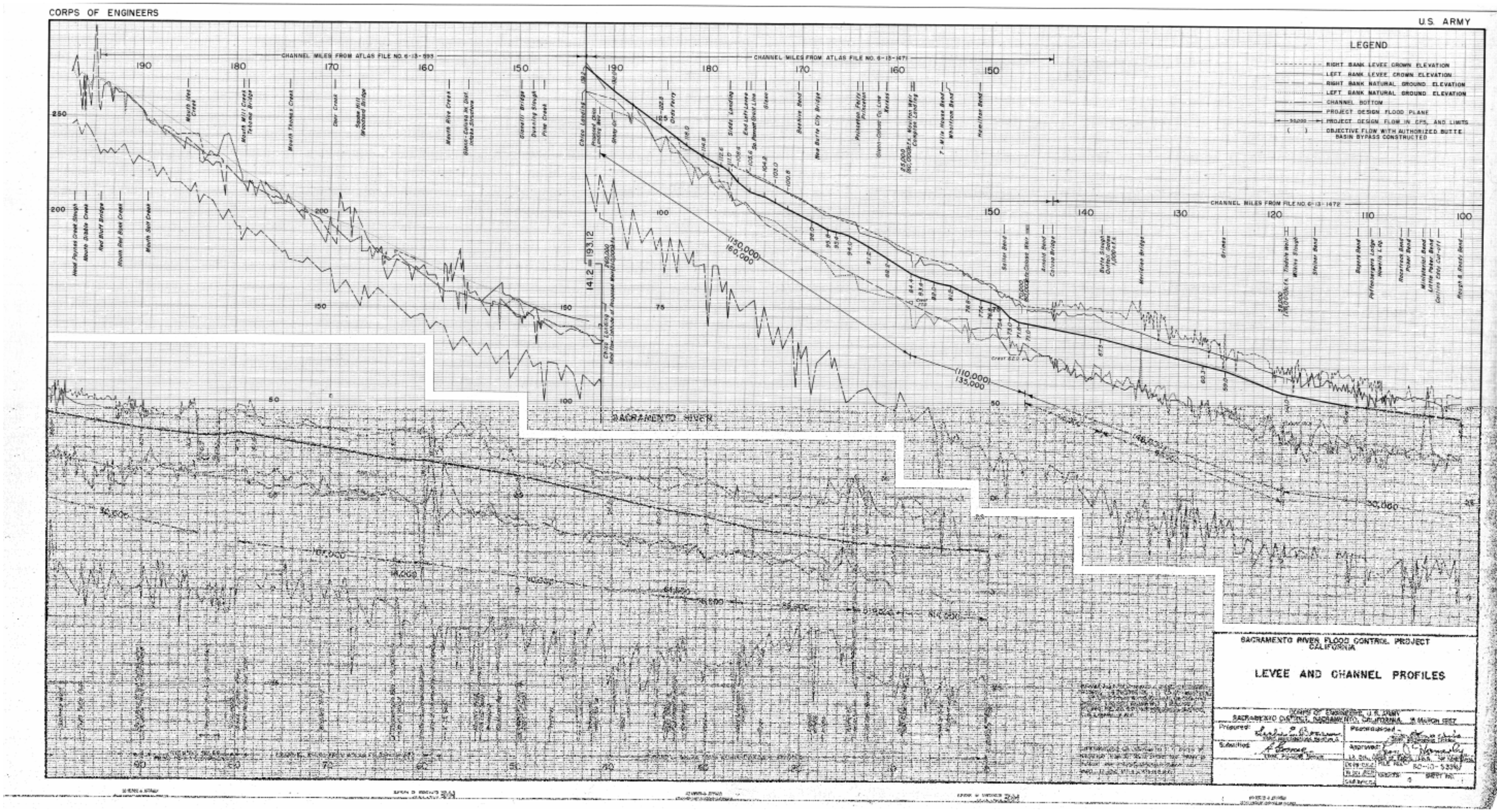


Figure 2. Example of system design profile (USACE 1957b)

3. Mathematical channel routing models were developed for each levee reach to define the relationship between flow, storage, and travel time. Best-available topographic data were used to define river geometry. Channel and overbank hydraulic roughness values (Manning's n values) were identified for each cross section, based on field observations, aerial photos when available, and engineering judgment.
4. A major flood event with sufficient data for calibration was selected.
5. Water surface elevation was computed for the event, and computed elevations were compared to observed. Where necessary and deemed appropriate, adjustments were made to cross sections or roughness values to improve the fit.
6. For each historical event, unimpaired flows were routed through the system and combined to establish the distribution of maximum flows under proposed project conditions.
7. From the distribution of flows, the final project design water surface profiles were computed.

Design of the SRFCP

In developing the SRFCP design, the following fundamental principles were identified (California Department of Public Works [DPW] 1925):

- The largest practical volume of water, consistent with the maintenance of good navigable conditions and without raising levees to excessive and dangerous heights or producing excessive seepage, was to be conveyed through the present river channels without inundating the adjacent floodplain.
- Weirs were to be located to minimize debris being carried into the bypasses from the river channel.
- Weirs were to be constructed with crest elevation so that as much water as possible remained in the river channels on the falling stage of the flood. The goal of this was to create what has been referred to as a self-cleaning system: The flows would scour the channel for the benefit of navigation and to increase the flood-carrying capacity.
- Bypasses were to have a uniform hydraulic grade line and velocity throughout, to the extent possible.
- For conservation of land, bypasses were to be located on *...the poorest and most alkaline land...*, or on land from which the spring floodwaters would drain early enough to permit summer cropping.
- Gravity drainage canals and pumping plants were to be constructed to drain interior floodplains from which the new levees would block natural flow to the river.

The historical flood event originally used to define design flows for the SRFCP was the 1907 flood. After the December 1937 flood, the design flows on the Feather River system were modified. Design flows for Butte Basin and on the

Sacramento River upstream of the Tisdale bypass were modified in 1951 to reflect results of a detailed study of that area. Minor modifications to design flows were made after a detailed study of 1955 flood records. The design profiles for various reaches were also reviewed, based on observed data, after the flood events of 1935, 1936, 1940, 1942, and 1950 (USACE 1957b). These reviews served as checks, and did not result in revisions to the design water surface profile.

Terrain data used to define cross sections for computation of design water surface profiles were based on the most recent river surveys. Much of the data was based on a survey of 1951. In some reaches, additional detailed surveys were made for final design (USACE 1957b).

Early water surface profiles were computed with Kutter's formula (DPW 1925). Later design profile computations used Manning's formula (USACE 1957a).

At least one design memorandum (USACE 1957a) noted that the design water surface profile was taken as the maximum of water surface profiles resulting from different hydrologic conditions. Appendix A of the reference details how this was done for the Natomas Canal (now known as the Natomas East Main Drainage Canal or Steelhead Creek) and the Natomas Cross Canal. On the Natomas Canal, hydrologic conditions considered were:

- Standard Project Flood (approximately 200-year) flow on tributaries to the canal, combined with moderate stage on the American River corresponding to a controlled flow of 115,000 cfs.
- Moderate (50-year) flow on tributaries to the canal, combined with maximum probable stage in the American River corresponding to a controlled flow of 115,000 cfs.

On the Natomas Cross Canal, hydrologic conditions considered were:

- 200-year event on tributaries to the canal, combined with moderate stage on the Sacramento River.
- 50-year event on tributaries to the canal, combined with project flood plane elevation on the Sacramento River.

For the SRFCP, freeboard of 3 feet was added to all river water surface profiles to set the minimum top of levee profile. An additional 2 to 3 feet of freeboard were added to wide reaches, such as the Sutter Bypass (with 5 feet total freeboard) and Yolo Bypass (with 6 feet total freeboard) to *...care for wave wash on those wide channels* (DPW 1925). The American River has 5 feet of freeboard at 115,000 cfs and 3 feet at 152,000 cfs (personal communication, Stephen Bradley, February 2007). One exception was made to the freeboard standard: About 5 miles of the western levee of the Natomas Canal was deficient 0 to 2 feet of freeboard. The Board agreed that it would not be economical to raise the levee to the SRFCP design level (USACE 1957a).

The performance of upstream levees and their connection to downstream levee performance was recognized in Appendix A of USACE 1957a. It noted that 3 feet of freeboard on the Natomas Canal and the Natomas Cross Canal represented a *...considerable factor of safety* because the starting elevation of the Sacramento River cannot increase significantly as any *...material increase in upstream Sacramento flows would inevitably cause extensive upstream levee failures which would allow large volumes of water to escape from the channels and prevent further rise at the mouth...*

Design of the LSJRTP

Project design flow determination for the LSJRTP was based on analysis of the floods of 1906, 1907, 1911, 1938, and 1950. 13 additional smaller floods were included to compute flow-frequency curves for the design study.

A Standard Project Flood was not developed *...since the area is almost entirely agricultural, with no urban centers of concentrated property values within the limits of the levee work* (USACE 1955a).

Project design flow selection for the LSJRTP considered the following factors (USACE 1955a):

- Type of area to be protected. Most areas were agricultural lands with no concentrated population within the floodplain.
- Extent of area subject to overflow.
- Phased development. The goal was to consider intermediate phases of project development, with timed construction of the reservoirs.
- Protection of Sacramento-San Joaquin Rivers Delta. The goal was to avoid increasing stage in the Delta as a result of channelizing flows. This, in turn, imposed height limits on upstream San Joaquin River levees.

Water surface elevation computations used Manning's equation. Manning's *n* values were estimated as a function of section hydraulic radius, using relationships previously defined for the Sacramento River. Data from the 1952 flood event was used for verification. If necessary, cross-section properties or Manning's *n* values were adjusted. For the great majority of locations, the final computed were reported to agree with observed river stages within 0.2 to 0.5 feet, while the maximum difference reported was 1.0 foot. High water mark data for the 1938 and 1950 floods also were used to verify hydraulic computations (USACE 1955b).

Intended level of protection

The SRFCP *Design memorandum no. 2* (USACE 1957a) describes the intended level of protection for urban areas in the SRFCP as follows:

The degree of protection to be provided by this unit of the Sacramento Flood Control Project is not specifically mentioned in the project document. However, the planned work will provide protection against a flood of standard project magnitude (estimated frequency of once in 200 years). This protection is consistent with that afforded urban areas through the balance of the Sacramento Flood Control Project.

Similarly, LSJRTP *Design Memorandum No. 1* (USACE 1955a) summarizes the intended level of protection for agricultural lands protected by the LSJRTP as follows:

In general, the aim has been to provide for a 40- to 50-year degree of protection after the authorized storage on the tributary streams has been completed.

Level of protection estimates for selected locations in the SRFCP and LSJRTP are provided in Table 3. These estimates were obtained from the indicated project design memorandums, and reflect conditions at the time of project completion, using frequency functions derived for the design studies. With respect to the SRFCP, Oroville Dam (Feather River), New Bullards Bar Dam (Yuba River), and Black Butte Dam (Stony Creek) had not yet been constructed. For the LSJRTP, level of protection estimates presumed completion of New Melones, New Don Pedro, Buchanan, and Hidden dams.

The SRFCP was designed, it appears, to provide a 200-year level of protection to urban areas. For agricultural areas in the Sacramento River basin, the SRFCP was designed to provide a 25-year level of protection. On the other hand, the LSJRTP was designed to provide a 40—50-year level of protection for what was considered agricultural areas only.

Recent analyses by the Sacramento District, USACE, and the California Department of Water Resources updated frequency functions for the system for the District's *Post-flood Assessment Report* (USACE 1999) and for the *Sacramento and San Joaquin River Basins Comprehensive Study Interim Report* (USACE and Reclamation Board 2002). Using these updated functions, presuming that levees function as designed, yields the estimates of current levels of protection shown in Table 4.

Table 3. Summary of intended level of protection[1]

River (1)	Location (2)	Design flow, cfs (3)	Return period, years (4)
Natomas Canal, Natomas Cross Canal, Pleasant Grove Creek Canal, East Side Canal	Back levees of RD 1000 and RD 1001	(varies by reach and within reaches)	200-year[2]
Feather River	Left bank from Nicolaus to Bear River	320,000	25-year[3]
Bear River	Left bank from Feather River to Western Pacific RR bridge	40,000	25-year[3]
Feather River	Both banks from Marysville to mouth of Bear River	300,000	25-year[4]
Bear River	Right bank from vicinity of Carlin Bridge to high ground	30,000	25-year[5]
Feather River	Left bank from Yuba River to 1 mile downstream	30,000	25-year[6]
Yuba River	Left bank from high ground at dredge tailings downstream to just beyond Southern Pacific RR bridge	120,000	20-year[6]
San Joaquin	Merced River to Tuolumne River	45,000	50-year[7]
San Joaquin	Tuolumne River to Stanislaus River	46,000	45-year[7]
San Joaquin	Stanislaus River to Old River	52,000	45-year[7]

Notes:
1. Not intended for use for evaluation of improvements as described herein.
2. SRFCP Design Memo. No. 2 (USACE 1957a)
3. SRFCP Design Memo. No. 8 (USACE 1958)
4. SRFCP Design Memo. No. 16 (USACE 1960b)
5. SRFCP Design Memo. No. 15 (USACE 1960a)
6. SRFCP Design Memo. No. 17 (USACE 1960c)
7. LSJRTP Design Memo. No. 1 (USACE 1955a)

Table 4. Summary of updated level of protection[1]

River (1)	Location (2)	Design flow, cfs[2] (3)	Return period, years[3,4,5] (4)
Sacramento	Butte City	160,000	50-year
Sacramento	Colusa	65,000	>100-year
Sacramento	Wilkensen Slough	30,000	10-year
Feather	above Yuba City	210,000	200-year
Feather	below Yuba River	300,000	125-year
Feather	Nicolaus	330,000	100-year
Sacramento	latitude Verona	450,000	50-year
Sacramento	latitude of Sacramento	590,000	100-year
Yuba	near Marysville	120,000	20-year
Bear		40,000	100-year
American	lower 5 miles	180,000	100-year
American	upstream	115,000	85-year
San Joaquin	near Maze Road bridge	46,000	50-year
San Joaquin	near Vernalis	52,000	90-year
Stanislaus	at Orange Blossom Bridge	12,000	200-year
Tuolumne	at Modesto	15,000	40-year

Notes:

1. Not intended for use for evolution of improvements as described herein.
2. Design flows from Corps levee and channel profiles for 1955 and 1957 design profiles.
3. Return periods shown are based upon flow only and do not consider levee performance, uncertainty, and other factors.
4. Return periods estimated from Corps' Comprehensive Study regulated flow frequency curves.
5. SRFCP level of protection estimates courtesy of MBK Engineers (E-mail communication from Joe Countryman, November 29, 2006).

3 Potential improvements to the system

The Sacramento River Flood Control Project and the Lower San Joaquin River and Tributaries Project successfully have protected lives and property in the Central Valley floodplains. However, improvements can increase the level of protection provided. Table 5 identifies the types of improvements and describes how each may increase the level of protection.

Table 5. Types of improvements

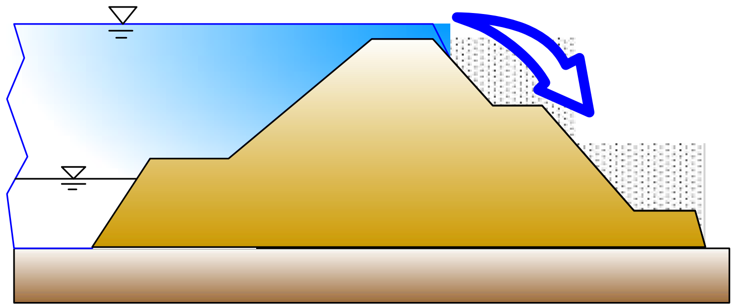
Accomplishment (1)	Example (2)	Classification (3)
Decrease the flow rate for a selected exceedence probability or design event	Improved reservoir operation could achieve this by storing more water now, then releasing that at a lesser rate later.	Structural improvement if construction required. Nonstructural improvement if only operation rules and procedures modified
Decrease the river stage corresponding to a given flow rate	Channel improvements, such as deepening or widening, would achieve this.	Structural
Decrease the floodplain stage corresponding to a given river stage	Levee improvements—levee raising, levee strengthening, and levee realigning or relocating—accomplish this.	Structural
Reducing the damage incurred by water reaching a given floodplain stage	This can be achieved with, for example, enhanced flood response and emergency planning.	Nonstructural, as no construction required

The impacts of improvements in all categories shown in Table 5 are of concern to the Board. However, in the remainder of this report, we focus on improvements to levees: raising, strengthening, realigning and relocating.

Levee raising

Description

A levee protects people and property by blocking the path of flow from the river onto the adjacent floodplain. If water level in the river channel rises above the top of the levee, however, the levee will fail to provide the anticipated protection. As illustrated in Figure 3, the levee will be overtopped, with flow over the levee onto the floodplain.



Yoon 2005

Figure 3. Levee overtopping

Raising a levee increases the elevation of the top of levee, thus reducing the likelihood of overtopping. To raise levee, we add material to the top of the levee. To ensure stability of the levee as it is raised, the width of the levee at its base must also be increased by the addition of material, typically on the land side of the levee. The width of the top of the levee must be increased also, to maintain a side slope on the levee that will be stable.

Information for determining impact of raising

Quantitative evaluation of the impacts of levee raising requires use of hydrologic, hydraulic, geotechnical, and economic information. This information can be developed and presented in a variety of formats. For illustration, the information is presented here as a set of graphs in Figure 4.

A *discharge-probability function* (Figure 4*a*) shows the likelihood that the annual maximum discharge at a location in the system will exceed (or equal) a selected value. Procedures for developing this function are well known. They include fitting a probability density function (a statistical model) with a streamflow record, using a conceptual rainfall-runoff-routing model with precipitation of known probability, and using empirical regression equations such as those developed by the US Geological Survey.

The discharge-probability function, commonly referred to as the *flow-frequency* function, may be altered by improvements in the system. For example, as noted above, if reservoir operations are enhanced, the flow rate for a given probability may decrease downstream of the reservoir. Similarly, if actions are taken that reduce the storage in a channel reach, the flow rate downstream of that reach may increase for a selected probability.

A *rating function* (Figure 4*b*) predicts stage (water level) in the channel, given the discharge. The rating function is developed by application of principles of hydraulics, with a mathematical model that represents the energy and momentum of flowing water, along with the conservation of volume of that water. Any modification to the channel geometry or channel roughness will affect the energy and conservation, yielding a change in the rating function. That change can be predicted with the hydraulics model.

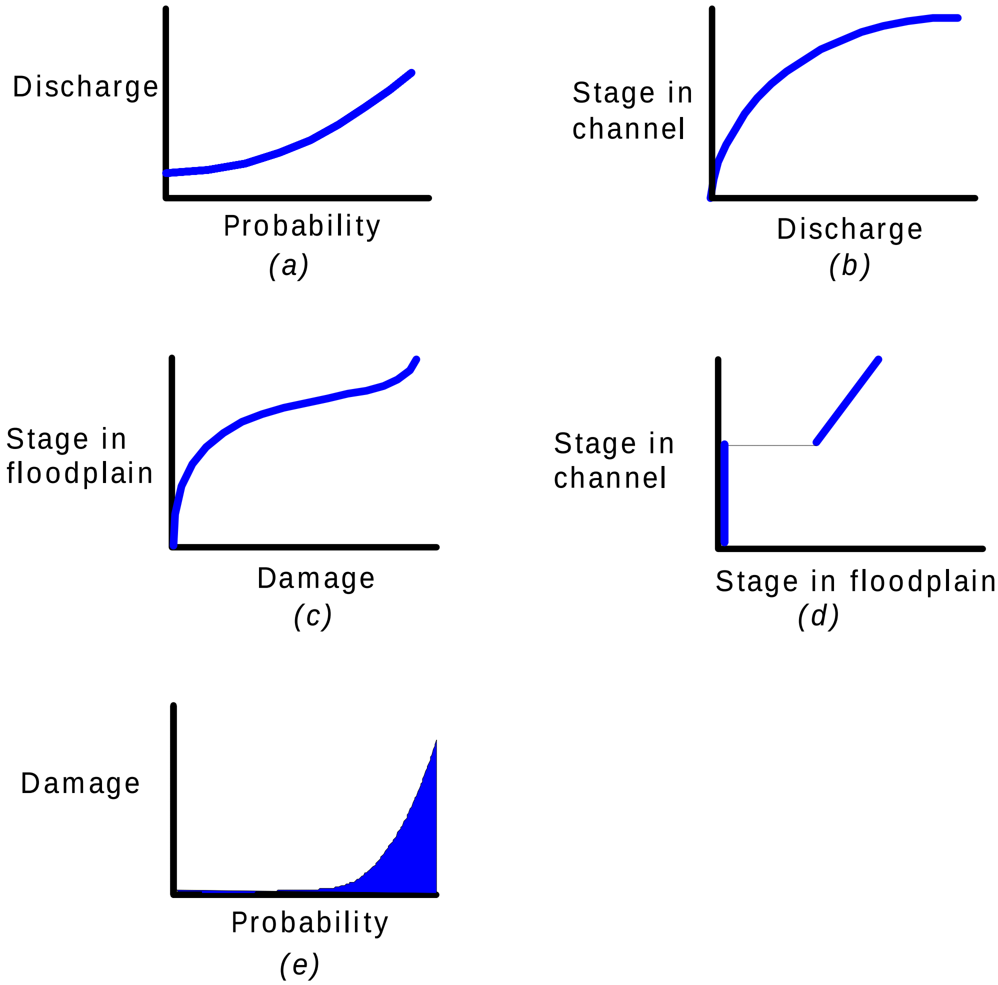


Figure 4. Illustration of functions useful for impact evaluation

Changes to the channel at one location may have an impact elsewhere in an interconnected system such as the Sacramento or San Joaquin. For example, if an improvement increases the velocity of flow in one reach of the system, the impact of that increase will be felt elsewhere. Consequently, the model used must represent the flow regime upstream and downstream of the location of proposed improvements to permit adequate assessment of changes to the rating function elsewhere in the system.

A *stage-damage function* (Figure 4*c*) predicts economic damage in the floodplain as a function of the stage in the floodplain. This function is developed from information about location and value of damageable property in the floodplain. Changes in the type or location of property in the floodplain will yield changes in this function. And the function is dynamic: If property is added to the floodplain as a consequence of development, the damage for a specified stage may increase.

In the absence of a levee, stage in the floodplain will equal stage in the channel when the channel capacity is exceeded. With a levee in place, a relationship of channel and floodplain stage (the *interior-exterior stage function* illustrated in Figure 4*d*) is required to predict the interior floodplain stage, given the river stage. As illustrated, for stages in the channel less than the elevation at which the levee fails to protect the interior area, the floodplain stages are 0.0. Only when the levee is overtopped or fails is the interior elevation greater than 0.0. This function also is developed with a hydraulics model that represents flow from the river into and across the floodplain. Changes to the levee will yield changes to this function.

The functions shown in Figure 4*a-d* can be combined mathematically to yield a *damage-frequency function* (Figure 4*e*). This function represents, for a certain floodplain or a portion of that floodplain, the likelihood that the annual maximum damage will exceed a specified value. As described in Appendix III, this function is the basis of expected annual damage (EAD) computations. The expected annual damage for a floodplain area within the system is the integral (shaded area under the curve) of this function. Any changes to the discharge-probability, stage-discharge, stage-damage, or interior-exterior stage functions, will cause a change in the damage-frequency function, and hence, a change in expected annual damage.

In common practice, for evaluation of impacts, the river channel is divided into reaches, and the adjacent floodplain is subdivided into *impact areas*, as illustrated in Figure 5. The reaches are selected so hydrologic, hydraulic, and levee geotechnical properties are relatively uniform within the reach. The impact areas are selected for uniformity of land use, economic value, and terrain.

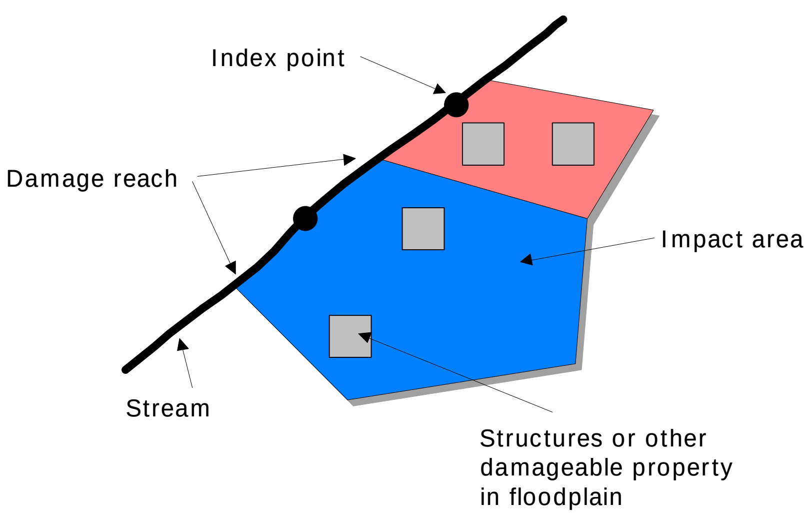


Figure 5. Impact area, index points, and damage reaches for system representation

For each impact area, an *index point* on the stream is identified. This is a point at which representative functions are specified for the reach and at which results of computation for the reach are reported.

Direct impact of levee raising

The intended consequence of raising a levee is to reduce the probability of overflow from the river onto the protected floodplain. From an analytical perspective, this means that the interior-exterior stage function at the point of the improvement is altered.

As illustrated in Figure 4*d*, until a levee is overtopped, the stage in the floodplain is zero (putting aside, for the moment, the risk of a levee breach that would permit flow into the interior area). With zero stage in the floodplain, the damage incurred is zero. As the levee is raised, the channel stage at which water overtops the levee and flows into the interior floodplain increases. This increases the flow that the channel can convey without overtopping. This, in turn, corresponds to a lower probability of exceedence and a higher level of protection.

Indirect impact of levee raising

Levee raising may have unintended impacts outside the area for which the raise improves flood protection. The change in top of levee elevation alters the channel geometry. This change may, in turn, affect flow rates and stages downstream of the improvement.

For example, in the leveed system illustrated in Figure 6, suppose that the levee that protects *Impact Area 3* from *River F* is raised from elevation 60 feet to 62 feet. This will increase the level of protection for the impact area, reducing the probability of overtopping, and hence, reducing the expected damage.

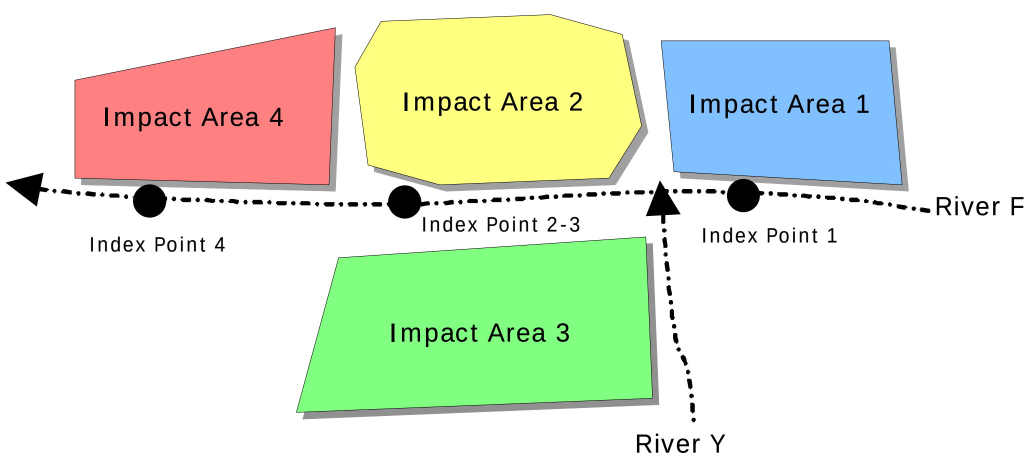


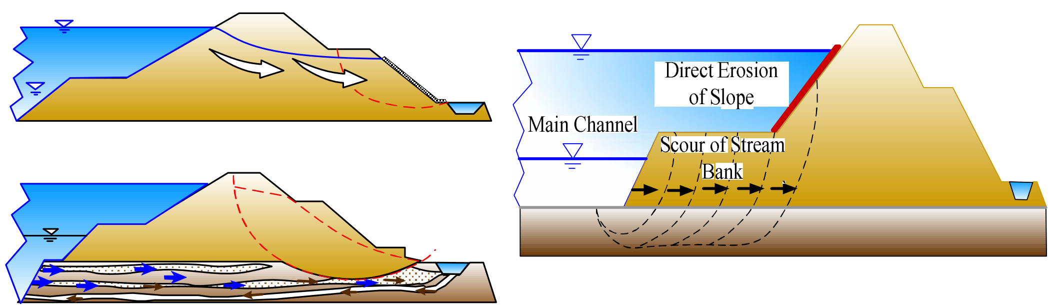
Figure 6. Example of interconnections in system

Now the flow is “controlled,” remaining in the channel at *Index Point 2-3* between elevation 60 feet and 62 feet, moving downstream. The storage that was provided incidentally and unintentionally by overflow into *Impact Area 3* at elevation 60 feet has been removed. This means that downstream flow rates at *Index Point 4* in the figure will be greater for a given probability. The greater flow rate at *Index Point 4* potentially will yield greater stage in the channel there. That may yield greater stage in the floodplain of *Impact Area 4*, and if the levee protecting *Impact Area 4* is not sufficiently high, it will be overtopped. The interior floodplain depth will increase, and damage will be greater.

Levee strengthening

Description

In addition to overtopping, levee failures may be a consequence of instability of the embankment due to seepage flow through or beneath the embankment (as illustrated by Figure 7*a*), erosion of the levee (Figure 7*b*) or failure due to flow around or through pump stations, gravity outlets, or other river structures that pass through the levee.



(a) Seepage *(b) Erosion*

Figure 7. Illustration of levee failure causes

Levee strengthening (also called hardening) includes actions that reduce the risk of a levee breach due to seepage, erosion, or failure due to flow around river structures. These actions are illustrated by Figure 8. In Figure 8, a slurry wall is shown at the core of the levee. This impervious wall limits seepage flow through or beneath the embankment, preventing the conditions shown in Figure 7*a*.

Seepage through the levee may lead to failure due to sliding of the interior face of the levee. The stability berm shown in Figure 8 is designed to reduce the risk of this. Figure 8 also shows how erosion of the channel side of the levee may be prevented with bank protection and fill.

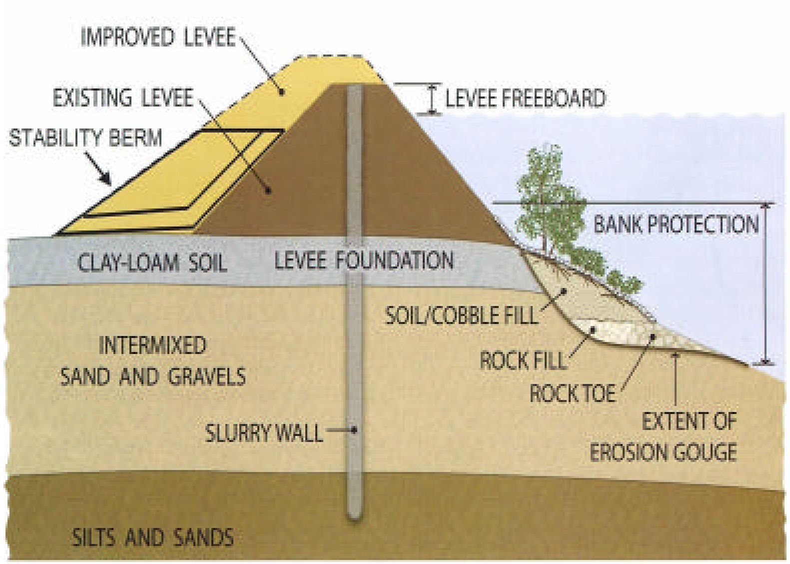


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Figure 8. Illustration of levee raising and strengthening

Direct and indirect impacts

The intended impact of levee strengthening is to reduce seepage, erosion, or flow through or around river structures, preventing levee "failure" except by overtopping.

The indirect, unintended consequences of levee strengthening may include:

- Increasing flow rate and channel stage elsewhere in the interconnected river system.
- Increasing the likelihood of levee failure elsewhere in the interconnected system due to migration of erosive forces.

The first consequence is an outcome of removal of the incidental storage that exists in the without-improvement condition. If a levee breaches or is overtopped, water from the channel enters and is stored temporarily in the interior floodplain. Availability of this storage, which comes at the expense of flooding of the interior area, reduces downstream flow rates. Removal of the storage increases downstream flow rate, and perhaps the stage, increasing the risk of levee failure there.

Similarly, the risk across the channel may increase as a consequence of strengthening. In Figure 6, for example, if the levee for *Impact Area 2* is strengthened, but the levee for *Impact Area 3* is not, the strengthening may increase the probability of failure of the *Impact Area 3* levee. The hardening may shift the distribution of erosive forces in the channel.

Appendix IV describes how uncertainty in levee performance can be accounted for explicitly in computation of performance and impact indices. As indicated there (and as illustrated by Figure 11 of the appendix), the uncertainty can be represented with a levee performance probability function.

With strengthening, the probability of failure of the levee is less for some or all channel stages. In the best case, the probability of failure is near 0.00 for all channel stages less than the top of levee. Thus, only when water in the channel reaches the top of levee does the interior floodplain flood depth exceed 0.

Levee relocation or realignment

Description

Repositioning a levee away from the channel, also known as levee setback, is illustrated in Figure 9. This improvement provides a wider channel cross section, which, in turn, permits a given flow rate to pass at a lower stage, as illustrated. Lower stage in the channel reduces the risk of floodplain inundation, as the risk of levee failure—either by overtopping or another failure mechanism—is reduced.

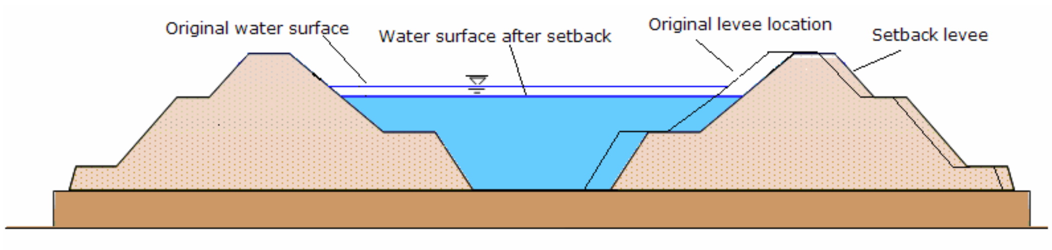

Figure 9. Levee setback

Levee realignment consists of straightening the channel, removing bends and oxbows. Water flows in a straightened channel with less energy loss, thus permitting a lower stage. As with the setback, this lower stage reduces the probability of overtopping or breaching and lowers the risk of levee failure.

Direct and indirect impacts

The intended, direct impact of levee relocation or realignment is reduction of channel water surface elevation (stage) at the location of the improvement. That reduction yields a reduction in floodplain stage, which, in turn, reduces damage and life risk.

Levee relocation may affect conditions outside the site of the relocation as a consequence of the hydraulic connectivity of the channels. For example, if the *Impact Area 2* levee in Figure 6 is moved back, the channel width increases there. The increased width yields a greater channel area and greater potential for storage of water in the reach. This storage may decrease flow downstream, also reducing stage there. On the other hand, the increased width and greater cross section area may increase the channel conveyance and thus increase the downstream flow rate and stage. The impact can be determined with a mathematical model of the interconnected channel hydraulics.

Similarly, levee realignment may have impacts elsewhere in the interconnected hydraulic system. If, for example, the *Impact Area 2* levee in Figure 6 is realigned, the stage for a given flow rate will decrease there. However velocities may increase there and downstream. These greater velocities increase the risk of erosion, thus increasing the risk of levee failure. (While this impact is not reflected directly in any of the functions illustrated in Figure 4, it can be predicted with models of sediment erosion and deposition.)

4 Impact measurement options

In this chapter, we propose quantitative measures or indices that may be used to describe impacts of improvements identified in Table 5. The focus here is on levee improvements, but the indices presented below are appropriate for measuring effects of any improvement.

The indices proposed measure physical, economic, statistical changes brought about by the improvements. For each index, we provide a brief description, followed by an overview of how the index can be calculated.

Baseline (without-improvement) condition

All the indices presented below quantify *changes* that are anticipated as a result of proposed improvements. Evaluating each index thus requires selection and evaluation of a baseline condition against which the proposed improved condition is compared.

For environmental impact assessment that satisfies requirements of the California Environmental Quality Act (CEQA) and for floodplain mapping that satisfies requirements of the National Flood Insurance Program (NFIP), this baseline condition is the current state of the system. For federal flood damage reduction planning, the baseline condition is extended to include a representation of the most-likely future state of the system, with authorized projects in place and with approved development plans followed, but absent the proposed improvements. The Corps of Engineers refers to this as the *without-project* condition.

For determination of the indices described herein, the without-project or without-improvement condition that forms the baseline for comparison is defined as follows:

- The baseline condition is a state of the system consistent with the intended design of the federal projects. This means, for example, that all project levees on the Sacramento River upstream of a proposed improvement site are considered to pass safely the design event without overtopping or breaching.
- Any temporary condition, such as erosion of a levee, is not considered as part of the baseline condition. The State of California has agreed to maintain the system as designed, so those conditions will be repaired.
- System improvements subsequently authorized by the federal government are included in the baseline condition. For example, authorized modifications on the lower American River are included as a component of the baseline condition.

With this baseline condition defined, the procedure for use of any index proposed below is as follows:

1. With the baseline condition as defined above, compute the index, following the procedure described, at each affected location. These locations include the site for which improvements are proposed, plus sites

upstream and downstream, as relevant to determination of the overall impacts.

2. With proposed project features included, compute the value of the selected index at the same locations.
3. Compare the with-improvement values to baseline values to determine if the impact is adverse and to determine if it is significant. If it is adverse and significant, prevention or mitigation may be necessary.

Index 1. Change in water-surface elevation or flow conveyance for system design flow

Description

This index measures upstream, downstream, or across-the-stream impact of a system improvement in terms of the difference in water-surface elevation, with and without the improvement, for the system design flow rate. In concept, the difference is computed and compared system-wide for the design flow rate. Practically, at locations far removed from the improvement, differences due to the improvement may not be detectable.

For this index, the probability of the design flow rate or any uncertainty about its magnitude is not relevant. As described in Chapter 2 of this report, the basis for design of the projects is a set of flow rates, based on historical events; probabilities were not explicitly selected as the basis for design.

Index determination

Determining the magnitude of this index requires these steps:

1. At the location of the improvement, determine the original design flow (consulting, for example, Figure 2 and similar graphs). Using an open-channel hydraulics model, determine the corresponding elevation.
2. For each relevant upstream and downstream location of interest, determine in a similar manner, the original design discharge and elevation at index points.
3. Modify the representation of the system channel network in the open channel flow model so that it now represents the improved condition. For example, if the levee is to be raised at the location of the improvement, the representation of the channel geometry should be modified in the model to reflect the increase levee height and the modified stream cross section.
4. Use the modified channel model, with the design discharge from steps 1 and 2, to compute modified water surface elevations at other relevant index points throughout the system.
5. Compare, for each index point, the original design profile elevation and the elevation with the improvement. If the elevation has increased and the increase is judged significant, we can conclude that the improvement

has an adverse impact at the index location. If the elevation has decreased, the improvement has a beneficial impact at the index location.

This index may alternatively be applied using velocity in the channel as the measure of impact. Steps in computation are similar to those listed above, but velocities computed with the hydraulics model are used instead of water surface elevations.

Index 2. Change in water-surface elevation for flow of specified annual exceedence probability

Description

This index measures the impact in terms of the difference in water-surface elevation, with and without the improvement, for a flow rate of specified annual exceedence probability. For example, this index might describe the impact in terms of increase in water-surface elevation for the flow rate with annual exceedence probability equal 0.01 (the 100-year flow). Similarly, this index could use a flow rate with annual exceedence probability equal to 0.02 (the 50-year flow), 0.005 (the 200-year flow), or another selected value. The difference in elevation is computed and compared system-wide for the selected annual exceedence probability.

(In the remainder of this document, we use the notation *p=0.01 flow* to represent the flow with probability equal 0.01, *p=0.005 stage* to represent the stage with probability equal 0.005, and so on.)

Index determination

Determining the magnitude of this index requires these steps:

1. Select the annual exceedence probability that is to be the benchmark for comparison and computation. Using a discharge-frequency function (such as illustrated by Figure 4a), estimate that flow quantile at the location of the improvement, but without the improvement in place.
2. Estimate the corresponding flow quantile at all relevant external index point locations.
3. Modify the representation of the channel network in the open channel flow model so that it now represents the improved condition. For example, if the levee is to be raised at the location of the improvement, the representation of the channel geometry should be modified to reflect the increased levee height.
4. Use the modified channel model, with the flow quantiles from steps 1 and 2, to compute water surface elevations at all relevant index point locations throughout the system.
5. For each index point, compare the modified elevation for the selected probability to the elevation with the unimproved condition. If the elevation increases for the selected annual exceedence probability, the

improvement has an adverse impact at the location, and a beneficial impact if the elevation has decreased, as measured by this index.

As with Index 1, this index could be altered to use velocity, rather than water surface elevation.

Index 3. Change in potential damage for system design flow

Description

This index measures the impact of an improvement in terms of the difference in potential damage incurred with and without the improvement, given occurrence of the system design flow. The difference is computed and compared system-wide for those flow rates.

This index explicitly incorporates and accounts for performance of system levees. That can be done in a probabilistic or deterministic manner. The former accounts for uncertainty in levee performance, while the latter puts this uncertainty aside for determination of the impact. This is described in more detail in Appendix IV.

Index determination

Determination of the magnitude of this index at any point within the system is similar to determination of Index 1. However, this index requires computation of the corresponding floodplain stage and the damage incurred due to failure at the project location and elsewhere.

To determine the magnitude of the index, the following steps are taken:

1. Repeat steps 1—4 from Index 1, determining for all relevant locations the design stage without and with the proposed improvement.
2. For each relevant index point location, use the interior-exterior function (as illustrated in Figure 4*d*) to predict the floodplain stage for the design event, without and with the improvement. (If desired or required, use a levee performance model, such as described in Appendix IV and illustrated by Figure 11 in that appendix, to account for uncertainty of levee performance.)
3. Using the appropriate stage-damage function (as illustrated by Figure 4*c*), determine the damage for each impact area caused by the design event, without and with the improvement.
4. Compute, for each impact area, the difference between the original design profile damage and the damage with the improvement. If the damage has increased, the improvement has an adverse impact at the location. If the elevation has decreased, the improvement has a beneficial impact at the index location.

Index 4. Change in potential damage for flow of specified annual exceedence probability

Description

This index measures the impact of an improvement in terms of the difference in potential damage that would be incurred with and without the improvement, given occurrence of a flow of specified probability. The difference is computed and compared system-wide for the selected probability. For example, this index may use the p=0.005 flow, computing potential damage system-wide for that event, without and with the improvement.

As with Index 3, this index incorporates explicitly the performance of system levees, in a deterministic or probabilistic manner.

Index determination

This index is determined with steps similar to the steps described for Index 3. However, instead of using the system design event, this index uses flow of selected probability.

That flow can be found at the improvement site by consulting the discharge-frequency function. Elsewhere in the system, new frequency functions must be determined if the improvements alter storage in the channels. From those new functions, flow is determined, then the corresponding stage and damage are found and compared to damage for the same probability, without the improvement.

So, for example, if the selected probability is 0.005, then damage will be found for impact areas throughout the system for the p=0.005 event, without and with the proposed improvement. And depending upon the properties of the improvement, the downstream p=0.005 flow, stage, and damage may increase or decrease.

Any increase in that damage indicates an adverse impact, as measured by this index.

Index 5. Change in expected annual damage

Description

This index measures the impact of an improvement in terms of the difference in expected annual damage (EAD), with and without the improvement. Expected annual damage is the long-term average of annual maximum damages; computation is described in Chapter 3 and Appendix III. For this index, EAD is computed and compared to the baseline value system-wide.

This measure accounts for the entire range of flows, including flow rates ranging from frequent to rare. As with other indices, it incorporates performance of levees deterministically or probabilistically.

Index determination

To determine the magnitude of this index within the system, procedures developed by the Corps of Engineers and summarized elsewhere in this document are used. Briefly, the steps that must be taken are these:

1. For the location of the improvement and for all other relevant locations in the system, develop without-improvement and with-improvement discharge-frequency functions, rating functions, interior-exterior functions, stage-damage functions, and levee performance models.
2. Following procedures developed by the Corps of Engineers, compute for each location the EAD without the improvement and with the improvement.
3. Compare the with-improvement EAD to the baseline value. If the EAD value with the improvement exceeds the baseline EAD value, the improvement has an adverse impact at the location, as measured by this index.

Note that this index is similar in concept to Index 4, but adds the step of considering a wide range of events and integrating them, rather than considering a single event.

Index 6. Change in portion of expected annual damage due to flows greater than system design flow

Description

This index is a variation of Index 5. This index measures the impact in terms of the difference in EAD, but it considers only the portion of EAD due to events greater than the design event.

As described in Chapter 3 and Appendix III, EAD for any impact area is computed by developing a damage-probability function, then integrating that function. Mechanically, this is equivalent to finding the area beneath the plotted function illustrated in Figure 4*e*. However, as illustrated in Figure 10, some portion of the area beneath the curve is attributable to events less than the design event, and some portion attributable to those greater. Index 5 considers both. For Index 6, only the portion attributable to events greater than the design event is included. Thus any increase of EAD due to changes in flow, stage, or damage for events smaller and more frequent than the design is not included.

Ideally, if an impact area is protected by a levee, the contribution to EAD for any event less than the design event for that levee will be 0. However, if a model of uncertainty of levee performance (such as that illustrated in Figure 11, Appendix IV) is included in the computation, some damage may be incurred as a consequence of rare levee failure during events smaller than the design event. This index does not consider that contribution.

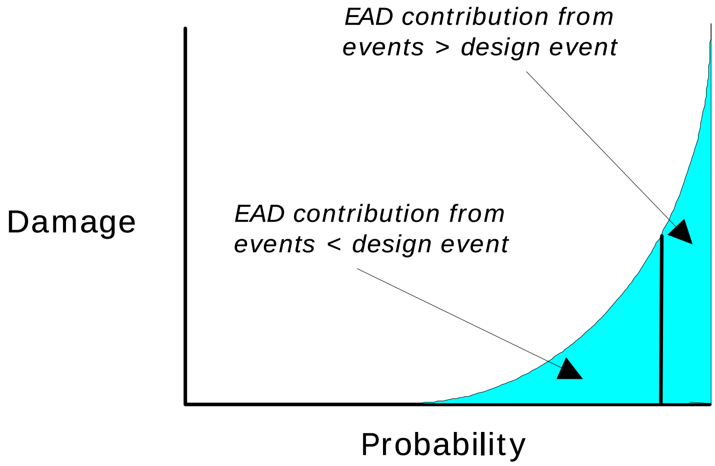

Figure 10. Partitioning of damage-probability function

For example, in Figure 6, if the *Impact Area 4* levee is designed to protect to elevation 22 feet, this index will compute and consider only damage for that impact area due to events with peak stage greater than 22 feet. If an upstream improvement increases only the frequency of stages less than 22 feet or alters the rating only for stages less than 22 feet, this index considers that improvement as having no impact.

Index determination

To determine the magnitude of this index within the system, steps similar to those described for Index 5 are taken to develop and integrate the damage probability function. However, the integration is limited to consider only events that exceed the design event for impact areas.

This computation cannot be accomplished directly with the current version of the Corps' HEC-FDA software application, which is the de facto standard for such computations. Work-arounds or modifications to the software will be required.

Index 7. Change in annual probability of inundation of interior floodplain

Description

At every floodplain location in the system, the probability of flooding is a number between 0 and 1. At some locations, this probability approaches 0, indicating that the likelihood of inundation is negligible. This may be a consequence of strong levees, high levee, higher ground in the floodplain, or some combination of these and other factors. At other locations, the probability of inundation is nearer 1, indicating a greater likelihood of flooding.

This index measures the impact of an improvement in terms of change in this probability of inundation with the improvement, compared to the probability without, computed at index points system-wide.

As described below, computation of this probability of inundation incorporates a prediction of the likelihood that the levees will protect the interior area from inundation. This can be done deterministically or probabilistically. For deterministic analysis, failure elevation must be selected and specified, perhaps as the design elevation without freeboard or some other logical value. For probabilistic analysis, a levee performance function, such at that show in Figure 11, is sampled.

Index determination

Briefly, the steps taken to compute this index without consideration of levee performance uncertainty are as follows:

1. For the baseline in each impact area that is to be considered, determine the levee failure elevation—the elevation at which water would flow into the interior floodplain. This could be the top of levee elevation, or it could be an elevation below the top, selected as the most likely failure elevation.
2. Using the rating function, determine the flow rate that corresponds to the failure elevation.
3. Referring to the flow-frequency function, find the annual exceedence probability associated with the flow rate from step 2. This is the annual exceedence probability (AEP), the value of this index.
4. Repeat steps 1-3 for the with-improvement condition, predicting the AEP for each relevant index location. Improvements that alter storage, and hence the flow–frequency relationship will change the AEP values in step 3.
5. Compare results of steps 3 and 4. If the AEP is greater with the improvement, then conclude that the improvement has an adverse impact for the impact area, as measured by this index.

This index can be computed also considering the uncertainty of levee performance. In that case, the sampling scheme including in computer program HEC-FDA (which is described in Appendix IV) can be used. With that scheme, rather than pre-selecting the failure elevation, the procedure will sample the levee failure probability relationship to predict if the levee provides protection at a given river stage.

Index 8. Change in probability of passing safely the design flow

Description

Rather than considering the entire range of possible flows, as does the EAD index described above, this index focuses only on the design flow at each location in the system and the likelihood, expressed as a probability, that this flow rate is passed safely.

At any location in the system, the probability of passing the design flow without inundation of the interior floodplain is between 0 and 1. At some locations, this probability approaches 0, indicating that the likelihood of inundation given the occurrence of the design event is negligible. Elsewhere, the probability may be near 1, indicating a greater likelihood of flooding should the design flow occur. Statisticians refer to this as a conditional probability: It expresses the likelihood of one event conditioned on (given) the occurrence of another. In this case, the statistic measures the probability of floodplain flooding, given occurrence of the design flow.

This index does not consider the probability of occurrence of the system design flow, which is an historical event for which probability is not relevant in this context. The design flow will not change as a consequence of improvements made; only the stage associated with the design flow will change. As flow throughout the system is, for all practical purposes, subcritical flow, this index will be affected by downstream or at-site improvements. Those improvements may increase the stages upstream for a given flow rate.

Much like Index 7, this index may incorporate a statistical model of the likelihood that the levees will protect the interior area from inundation.

Index determination

Presuming that levee performance uncertainty is considered, the steps that must be taken to compute this index are as follows:

1. For each impact area that is to be considered, determine the system design flow.
2. Without and with the improvement in place, use a hydraulics model to determine for the impact area the channel stage corresponding to the design flow.
3. Use a levee performance model to predict if the levee protects the interior area for the given stage from step 2. With the HEC-FDA program, this step and step 2 are repeated many times, sampling the levee performance function. The average frequency of exceedence is the probability of passing the event.
4. Compare results for the without and with improvement cases. If the with-improvement probability exceeds the without-improvement probability, conclude that the improvement has an adverse impact for the impact area, as measured by this index.

Index 9. Change in probability of passing safely flow of specified probability

Description

Much like Index 8, this index measures impact in terms of change in the likelihood of passing safely a selected flow. In this case, that is a flow of selected probability. For example, this index may measure the impact in terms of changes in the ability of the system to pass safely the p=0.005 flow for a dense urban area or the ability to pass safely the p=0.01 flow for an agricultural area.

[This index, applied to the p=0.01 event, is the current standard for levee certification by the Corps. In that context, the index is referred to as the *level of assurance* or the *conditional non-exceedence probability* (CNP). For certification, the Corps requires that the probability of passing safely the p=0.01 flow is at least 0.90.]

If an improvement alters the flow regime in the system, the magnitude of the flow associated with the target probability may increase, leading to greater stage for the selected probability. Similarly, stage associated with the flow for the selected probability may increase if channel conveyance changes. Either change will yield a change in this index.

Like Index 8, this index is informative when it incorporates a measure of the likelihood that levees will protect the interior area from inundation.

Index determination

Presuming, again, that levee performance uncertainty is considered, the steps taken to compute this index are as follows:

1. For each impact area that is to be considered, establish the without-improvement stage-frequency function and the with-improvement stage-frequency function. This step requires application of a system-wide hydraulics model. Upstream inflows for the model are determined from flow-frequency functions, and downstream flows and stages are found via routing.
2. From the stage-frequency functions, select the stage for the target probability. For example, if the target is the p=0.01 event, select the p=0.01 stage, without and with the improvements. (Note that the Corps' HEC-FDA application will do this by sampling the frequency function and errors in that, as described in Appendix IV.)
3. Use a levee performance model to predict if the levee protects the interior area for the stage from step 2. If the HEC-FDA program is used with sampling, this step and step 2 are repeated many times, sampling the levee performance function. The average frequency of exceedence is the probability of passing the event.
4. Compare the results without and with the improvement. If the probability of passing the event with the improvement is less that the probability

without the improvement, the improvement has an adverse impact for the impact area, as measured by this index.

Summary of indices

Table 5 is a summary of the indices proposed for measuring impacts of improvements proposed to the system.

Practical considerations for application of indices

Certain practical matters must be considered in selection and use of any of the indices proposed. These include:

- *Hydraulic modeling software*. A system-wide hydraulics model is necessary for comprehensive, fair evaluation of the indices proposed. Such a model should be identified and agreed upon for use.

  This comprehensive model (or integrated set of models) should incorporate the best-available data system-wide, including topographic and bathymetric surveys, levee profiles and geotechnical properties, channel roughness model parameters, and so on. The model should use standard-of-practice software, such as the widely known and used Corps of Engineers' HEC-RAS program. Qualified experts should review the model.

  Ideally, the system-wide hydraulics model will be freely and readily available to applicants and reviewers. These users should update the model with new data gathered, improved estimates of model parameters, and so on. (This sharing for data and information is consistent with current practice: Modelers from the Corps of Engineers, DWR, and local consultants routinely refine and exchange models of system channels.)

- *Risk evaluation software*. For those indices that include statistical or economic measures of impacts, reliable software must be identified and agreed upon for use.

  While all the indices could, in concept, be computed with spreadsheets, this method of computation is impractical for all but the simplest cases. Auditing and reviewing computations and results would be difficult, and data management for a system-wide assessment would be problematic.

  To compute conveniently the indices that consider exceedence probability or economic impact, reliable "industrial grade" software should be identified and used. The Corps' Flood Damage Analysis program (HEC-FDA) is a candidate for this. This computer program implements risk and economic analysis methods developed by the Corps and required by Corps *Engineering Manual (EM) 1110-2-1419*.

  The current version of the HEC-FDA program, version 1.2, released by the Corps in 2000, has been used by the Corps, DWR, and applicants for a variety of flood management studies in the Sacramento and San Joaquin River basins. Users have identified and learned to work around various shortcomings of this application.

The Board and DWR staff should review critically the current version of HEC-FDA software and gain agreement from experts in the community that it is appropriate and acceptable to use for the analyses required. If it is not, and if one of the statistical or economic indices is selected, an alternative analysis tool should be identified.

- *Data requirements.* Indices that require analysis of flood damage require considerable data for computation. These data include inventories of damageable property in the floodplain, including descriptions of structure types, values, and locations. Acquiring, processing, managing, and analyzing these data can be time consuming and costly. Unless the burden of that effort can be shared, determining these indices will be difficult for applicants with limited resources.
- *Expertise required*. Evaluation of the various indices proposed may require—depending upon the index selected—acquiring, processing, managing, and analyzing complex hydrologic, hydraulic, geotechnical, and economic data, and synthesizing and interpreting results of this analysis. The expertise necessary to accomplish the computations successfully is considerable, and the depth of understanding necessary to interpret and explain the results of certain indices is extensive—especially those indices that involve economic and statistical analysis. While this is not beyond the expertise of the local engineering and scientific community and Board staff, it does go beyond common hydraulic engineering analyses required for comparing water surface profiles.
- *Consideration of the study area for system-wide impact analysis*. Although we propose herein that impacts be evaluated system-wide, we note that for practical application, the system may be divided into independent components. This will reduce the overall effort. For example, for evaluation of improvements in the upper Sacramento River, analysis of the lower Sacramento likely is not required. The General Manager, Chief Engineer, or Board staff, in cooperation with the applicant, can make this determination.
- *Computational tolerances*. Hydraulic models and risk evaluation software have limitations. Solutions found are accurate to a specified tolerance, depending upon computational methods and the data used. What may appear to be an impact—when judged by simple comparison of computed values—could be a consequence of lack of accuracy or precision in computations. For example, a computed difference of 0.01 foot in water surface elevations may be less than the tolerance of the hydraulics model or within the error of the terrain or bathymetric data used.

  Similarly, impacts implied by small differences in annual exceedence probabilities may, in fact, be a consequence of minor changes in inputs to the analysis tools. For example, shifting stages in the levee performance function illustrated in Figure 11 by a 0.01 foot may shift the AEP (Index 7) from an acceptable 0.005 (200-year level of protection) to an unacceptable 0.0051 (196-year level of protection.) This sensitivity and uncertainty should be acknowledged and considered as decisions are made.

Table 6. Summary of indices

	Option (1)	Description (2)	Comments (3)
1	Change in water-surface elevation or flow conveyance for system design flow	Measures upstream, downstream, or across-the-stream impact of a system improvement in terms of the difference in water-surface elevation, with and without the improvement, for the system design flow rate.	• System design flow rate is established value, not subject to change. • Uses well-known hydraulic analysis procedures with design flow rate to determine if water surface elevation (or velocity) change with proposed improvement. • Only considers changes in elevation or velocity without regard to economic consequences of changes. • System-wide hydraulic model needed to evaluate change fairly throughout the system.
2	Change in water-surface elevation for flow of specified annual exceedence probability	Measures impact in terms of difference in water-surface elevation, with and without the improvement, for flow rate of specified annual exceedence probability.	• Flow rate for selected annual exceedence probability must be determined. May vary as flow-frequency functions updated. • Uses well-known hydraulic analysis procedures to determine if water surface elevation (or velocity) increase. • Only considers changes in elevation or velocity without regard to economic consequences of changes. • System-wide hydraulic model needed to evaluate change fairly throughout the system.

Option (1)	Description (2)	Comments (3)
3 Change in potential damage for system design flow	Measures impact of improvement in terms of difference in potential damage with and without improvement, given occurrence of system design flow.	• System design flow rate is established value, not subject to change. • Uses well-known hydraulic and economic analysis procedures to determine water surface elevation and corresponding damage without and with proposed improvement. Software available for evaluation. • System-wide hydraulic model needed to evaluate change fairly throughout the system. • Levee performance assumption or probabilistic model required. • Property inventory required for damage analysis.
4 Change in potential damage for flow of specified annual exceedence probability	Measures impact of improvement in terms of difference in potential damage incurred with and without improvement, given occurrence of flow of specified probability	• Flow rate for selected annual exceedence probability must be determined. May vary as flow-frequency functions updated. • Uses well-known hydraulic and economic analysis procedures to determine water surface elevation and corresponding damage without and with proposed improvement. Software available for evaluation. • System-wide hydraulic model needed to evaluate change fairly throughout the system. • Levee performance assumption or probabilistic model required. • Property inventory required for damage analysis.

Option (1)	Description (2)	Comments (3)
5 Change in expected annual damage	Measures impact of improvement in terms of difference in expected annual damage, with and without improvement	• Flow rates for range of annual exceedence probabilities must be determined. These may vary as flow-frequency functions updated. • Uses well-known hydraulic and economic analysis procedures to determine water surface elevation and corresponding damage without and with proposed improvement. Software available for evaluation. • System-wide hydraulic model needed to evaluate change fairly throughout the system. • Levee performance assumption or probabilistic model required. • Property inventory required for damage analysis.
6 Change in portion of expected annual damage due to flows greater than system design flow	This is a variation on Index 5; it measures impact in terms of difference in EAD, but considers only contribution to EAD from events greater than design event.	• Annual exceedence probabilities must be determined for range of flow rates greater than system design flow. These may vary as flow-frequency functions updated. • Uses well-known hydraulic and economic analysis procedures to determine water surface elevation and corresponding damage without and with proposed improvement. Software available for parts of evaluation, but computation will require Corps' cooperation to modify program HEC-FDA. • System-wide hydraulic model needed to evaluate change fairly throughout the system. • Levee performance assumption or probabilistic model required. • Property inventory required for damage analysis.

Option (1)		Description (2)	Comments (3)
7	Change in annual probability of inundation of interior floodplain	Measures impact of improvement in terms of increase in probability of inundation with improvement, compared to probability without, at index points system-wide.	• Flow rates for range of annual exceedence probabilities must be determined. These may vary as flow-frequency functions updated. • Uses well-known hydraulic procedures to determine water surface elevation without and with proposed improvement. Software available for evaluation. • Levee performance assumption or probabilistic model required. • System-wide hydraulic model needed to evaluate change fairly throughout the system.
8	Change in probability of passing safely design flow	Measures impact of improvement in terms of change in probability of passing safely design flow without and with improvement, at index points system-wide.	• System design flow rate is established value, not subject to change. • Uses well-known hydraulic analysis procedures to determine water surface elevation corresponding, then integrates that with models of interior and exterior hydraulics and levee performance. Software available for this computation. • Levee performance assumption or probabilistic model required.
9	Change in probability of passing safely flow of specified probability	Measures impact in terms of change in probability of safely passing flow of specified probability.	• Design standard (probability) must be selected, and flow rate for that probability must be determined. Flow rate may vary as flow-frequency functions updated. • Once flow rate determined, uses well-known hydraulic analysis procedures to determine water surface elevation. Integrates that with models of interior and exterior hydraulics and levee performance. Software available for this computation. • System-wide hydraulic model needed to evaluate change fairly throughout the system. • Levee performance assumption or probabilistic model required.

5 Prevention and mitigation options

Actions can be taken to prevent or mitigate adverse impacts identified with the indices described above. Table 6 includes options that do so; this list is intended as a guideline only.

Options shown include both structural and nonstructural options. Structural options reduce or eliminate the impact by managing the waters, while nonstructural options manage the consequences of the impact without eliminating the impact.

The options shown may be used alone or in combination. Depending on the situation, other mitigation efforts may be appropriate.

Table 7. Prevention and mitigation options

	Option (1)	Description (2)	Strength (3)	Weakness (4)
1	Avoid the impact by disallowing the improvement.	This option eliminates the need to mitigate, as it does not permit actions for which a significant adverse impact is shown with the selected impact index. For example, if a proposed levee raise will increase EAD a significant amount at a downstream impact area, this option would disallow the raise.	Ensures that those outside the area of direct benefit of the improvement are not harmed in any way by the proposed improvement.	Could stall or stop work to improve flood protection for existing development, could stall or stop further development of undeveloped property, and could limit intensification of current use.
2	Mitigate adverse impact with construction of structural measure(s).	This mitigation option reverses all or some portion of the off-site adverse impact of an improvement by designing and implementing an offsetting structural measure. For example, if an upstream levee improvement raises the downstream channel stage for the design event, this alternative could include raising the downstream levee enough to restore the affected impact area to the without-project level of protection. The cost of this can be assigned to the party responsible for the increased risk.	Permits continued improvements to system. Eliminates the adverse impact.	May mitigate the adverse impact of one improvement by creating an adverse impact elsewhere. If construction cost is assigned to upstream interest, that cost may be so great that it will prohibit any improvement, as the total system cost may exceed the benefit of the improvement.
3	Notify those who are adversely impacted (as already required by the Board)	This mitigation option requires notification of property owners and occupants of an impact area if an improvement will affect them adversely, as measured by the selected index. The formal notification will provide those affected with information about the risk, thus providing an opportunity to protect themselves.	Allows continued improvements to system. Provides an opportunity for property owners and floodplain occupants to protect themselves from damage due to any increase in flow or stage. For example, with information provided, property owners may decide to develop and deploy enhanced emergency flood response plans.	Does nothing to reduce flow, stage, or likelihood of levee failure for an affected impact area.

Option (1)		Description (2)	Strength (3)	Weakness (4)
4	Reimburse for increased damage potential (single event or expected damage)	This option mitigates the adverse off-site economic impact of an improvement by reimbursing those who may suffer from increased damage for the value of that incremental damage. The reimbursement may equal: (a) Potential increment in EAD (equal the with-improvement EAD less without-improvement EAD) (b) Potential incremental damage incurred for a selected flood event. For example, if the design standard selected is the 200-year event, the reimbursement is the increment in damage for the 200-year event due to the improvement proposed. Payment may be made annually or as a lump-sum present-value equivalent of the additional EAD over the project life.	Allows continued improvements to system. Makes whole those damaged.	Does not eliminate the damage. Considers only direct, tangible cost due to an improvement. Does not consider loss of life or injury due to an improvement.
5	Insure those with increased damage potential	This option provides insurance to reimburse those damaged if and when they are damaged. The reimbursement equals the incremental damage incurred as a consequence of improvements. Those who create the adverse impact pay the insurance premiums.	Allows continued improvements to system. Makes whole those damaged, if and when they are.	Does not eliminate damage. Considers only direct, tangible cost due to an improvement. Does not consider loss of life or injury due to an improvement. May require new institution to administer insurance program.
6	Collect impact fee to offset increased construction cost for system-wide plan of flood control	This option acknowledges the goal of the state plan of flood control to provide protection throughout the Central Valley. If improvements made will increase the cost of achieving that, this option requires those who make the improvements to offset the increased cost.	Allows continued improvements to system.	Does not eliminate damage.

	Option (1)	Description (2)	Strength (3)	Weakness (4)
7	Pay the cost associated with any increased damage, if and when it occurs	Much like Option 4, this option mitigates the adverse external economic impact of an improvement by reimbursing those who are damaged. However, unlike Option 4 or Option 5, this option requires payment if and only if damage is incurred, based upon actual claims. The payment is limited to the increment due to the improvements made.	Allows continued improvements to system. Makes whole those damaged, if and when they are.	Does not eliminate damage. Relies on the ability to pay by those causing damage; this may change over time. Determination of incremental damage due to improvements after failure may be difficult forensic analysis problem to solve.
8	Other types of insurance	Identify property upstream and downstream that could be purchased or leased to provide the additional storage requirements during a large storm event. This will help insure the safety of others in the system.	Allows continued improvements to system.	May be difficult to find enough land to purchase or lease to provide adequate mitigation. Cross-governmental jurisdictional issues may make implementation difficult.

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Appendix II. Glossary

annual exceedence probability	Likelihood, measured as a probability between 0 and 1, that a random event (flow, stage, damage, etc.) will exceed a specified magnitude in any year.
conditional exceedence probability	Probability (usually annual) that a specified threshold will be exceeded, given the occurrence or exceedence of another related event.
conditional non-exceedence probability	Probability (usually annual) that a specified threshold will not be exceeded, given the occurrence or exceedence of another related event. Commonly abbreviated CNP.
design flood	"[T]he flood against which protection is provided or may eventually be provided by means of flood protection or control works, or that flood which the board otherwise determines to be compatible with future developments" (Water Code). This is also known as the design event. The corresponding discharge is referred to as the design discharge or flow, and the corresponding water surface elevation is referred to as the design stage or elevation.
economic impact	As used herein, this is the benefit or cost accruing as a consequence of an action taken. It is related to hydraulic impact, but extends that concept to include the consequence, for example, of increasing flood damage due to increasing stage.
expected annual damage	The long-term average of annual maximum damage at a location. Commonly abbreviated EAD. This is computed as the integral of the damage-probability function. Depending on the method used, EAD computations may include or ignore uncertainty of contributing factors.
frequency function (or curve)	A mathematical or graphical representation of probability of equaling or exceeding various magnitudes of some random variable.
HEC-FDA	US Army Corps of Engineers Hydrologic Engineering Center's flood damage analysis software program. This program computes expected annual damage, conditional non-exceedence probability of design events, and annual exceedence probability. It uses a sampling technique to account for uncertainty of inputs.

hydraulic impact	Change in hydraulic condition, such as water surface elevation, due to a system modification.
hydraulics model	Physical or mathematical representation of a river channel. For evaluation of impacts considered here, such a model is used to calculate water surface elevation (stage) along a channel for a specified flow rate.
inundation damage	Damage incurred due to submergence of property.
mitigation	Act of making less severe or eliminating the impacts of a project.
exceedence probability	Measure of likelihood that a specified flow, stage, damage, or other threshold will be exceeded. Generally expressed on an annual basis, and then referred to as annual exceedence probability, or AEP.
probability density function	A mathematical model of relationship of magnitude of flow, stage, damage, or another state or condition to the likelihood of occurrence of that state or condition. Often abbreviated PDF. For example, a discharge PDF describes the probability of occurrence of various discharge magnitudes.
rating function (or rating curve or table)	A mathematical or graphical relationship between stage (water surface elevation) in a channel and flow rate in the channel.
recurrence interval, return interval, return period	Average time between exceedences of a threshold or occurrences of a condition or state. Commonly estimated as the reciprocal of annual exceedence probability.
residual damage	Potential property damage remaining at a location with all prevention and mitigation measures in place and fully functional.
residual risk	Likelihood of flooding or damage at a location with all prevention and mitigation measures in place and fully functional. Commonly expressed in term of annual exceedence probability.
risk	Product of probability of occurrence of an event and the consequence of that occurrence. Also used commonly to define the long-term probability of exceedence of a threshold, given annual probability. In that case, risk is computed as $R=1-(1-p)^n$ in which R=probability of 1 or more exceedences in n years and p=annual exceedence probability.

stage-damage function (or curve)	Relationship, for a structure or a grouping of structures, of damage to stage or water surface elevation at the site.

Appendix III. Expected annual damage computation procedure

This appendix describes computation of expected annual damage (EAD). That computation is required for several of the indices proposed herein. Additional details are provided in various documents available from the Corps of Engineers, as is software for EAD computation.

Theoretical background

In mathematical terms, if we let X represent the value of annual flood damage, then the expected value of annual damage, $E[X]$, is computed as

$$E[X] = \int_{-\infty}^{\infty} x\, f_X(x)dx$$

in which x = the random value of annual damage that occurs with probability $f_X(x)dx$. With this, all the information about the probability of occurrence of various magnitudes of damage is condensed into a single number by summing the products of all possible damage values and the likelihood of their occurrence.

In the equation, $f_X(x)$ is what statisticians refer to as the *probability density function* (PDF). In hydrologic engineering, an alternative representation of the same information, the so-called *cumulative distribution function* (CDF), is more commonly used. This is defined as

$$F_X(x) = \int_{-\infty}^{x} f_X(u)du$$

This distribution function, also known as a *frequency function*, describes the likelihood that annual maximum damage will not exceed a specified value X. Alternately, by exchanging the limits of integration, the CDF could define the probability that the damage will exceed a specified value. In either case, the CDF and PDF are related as

$$\frac{dF_X(x)}{dx} = f_X(x)$$

so the expected value of annual damage—the EAD—is

$$E[X] = \int_{-\infty}^{\infty} x \frac{dF_X(x)}{dx} dx$$

Practical method of computation

In concept, the damage-frequency function required for computation of EAD could be derived by collecting annual damage data over time and fitting a statistical model. In most cases, such damage data are not available or are sparse for existing conditions. Further, the damage data never are available for proposed conditions, so such collection and fitting is not viable.

The solution is to derive the damage-frequency function for existing or proposed, present or future conditions through collection, analysis, and transformation of available hydrologic, hydraulic, and economic information. This was illustrated in Figure 4.

This transformation and integration task can be completed using the Corps of Engineers' computer program HEC-FDA (USACE 1998). The HEC-FDA program computation methods are based on the concept that the average of damages that are incurred over a very long period will approach the true EAD. HEC-FDA uses a statistical sampling method to synthesize a long sequence of flood flows. The program then uses a rating function to find corresponding stages, and an interior-exterior relationship to find corresponding interior floodplain stages. Damages incurred due to these interior stages are transformed with a stage-damage function to synthesize a long record of annual damages. Those are averaged. This process is equivalent to developing and integrating the damage-frequency function.

Appendix IV. Uncertainty analysis

Steps identified for determination of indices proposed in earlier sections of this report do not account for the uncertainty in knowledge of the hydrologic, hydraulic, economic, and geotechnical inputs and information. That uncertainty is addressed briefly in this appendix, and methods for incorporating measures of the uncertainty are described briefly.

Levee performance uncertainty

Levee performance is critical to determination of impacts within the flood control system. If levees perform as designed, they prevent flooding of the interior floodplain unless and until water flows over the top of the levee. On the other hand, if a levee is breached due to erosion or other causes, water will flow into the interior floodplain before overtopping elevations in the exterior channel are reached.

This uncertainty about levee performance can be accounted for explicitly in determination of impact indices proposed herein. To do so, a mathematical representation of the likelihood of levee failure is developed and incorporated in the computations. One such representation is illustrated in Figure 11.

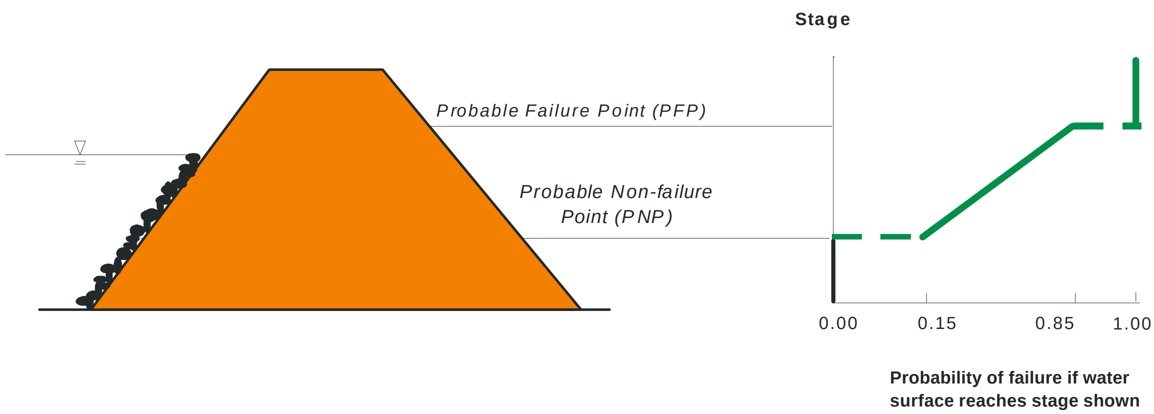

Figure 11. Levee performance model

In the figure, the probability of a levee failure such that water enters the protected floodplain is shown as a function of the water surface elevation in the exterior channel. (Although the function illustrated here is simple and linear, that is not a requirement for the analysis.) In this illustration, for some low elevation identified as the *probable non-failure point* in the figure, the likelihood of failure and flooding is small: 0.15 in the figure. For elevations below the probable non-failure point (PNP), the likelihood of failure is considered 0.00. As the water surface elevation in the channel increases, the likelihood of failure increases in the function shown. At a channel water surface elevation labeled *probable failure point* in the figure, the probability of failure with flooding into the interior floodplain increases to 0.85. For elevations above the probable failure point (the PFP), failure is considered a certainty.

The algorithm included in the Corps of Engineers' HEC-FDA program can use such a levee performance probability function. As the algorithm synthesizes a long record of flows and corresponding channel stages, it samples the levee performance function to consider the likelihood of an unpredictable, unanticipated levee failure, even as the levee is not overtopped. If such a failure is simulated, corresponding damage is found with the interior-exterior stage and stage-damage functions. That damage is included in the computation of EAD.

Uncertainty of other information

Other information required for evaluation of the proposed impact indices is uncertain. If these additional uncertainties are described with mathematical models similar in concept to the model of uncertainty of levee performance, the influence of those uncertainties also can be incorporated in the indices that are computed.

Hydrologic engineers and scientists have long acknowledged that flow-frequency functions based upon data sets with only 25-100 years of streamflow data yield results that are highly uncertain in the extremes. For example, a p=0.01 discharge that is estimated with only 25 years of observations will be highly uncertain. That short record could fail to include any large flow events that are in the range of the true 100-year flow, or it could include an extraordinarily large number of such events. In either case, conclusions about the 100-year flow drawn from analysis of the small sample will be incorrect.

We can account for the impact of this uncertainty analytically in the damage computation by introducing another probability density function that describes the range of and likelihood of errors in flow estimates for a given annual exceedence probability. This is illustrated in Figure 12. There, the gray curve shown for a selected probability represents the distribution of possible errors in estimating the discharge with a small sample of flow observations. As the sample increases in number, the spread of the errors is reduced.

Similar probability functions can be developed to model errors in estimating the stage, given the discharge, and errors in estimating the damage, given the floodplain stage. With these, we can account for the likelihood of and accumulated impact of those errors in computation of the impact indices.

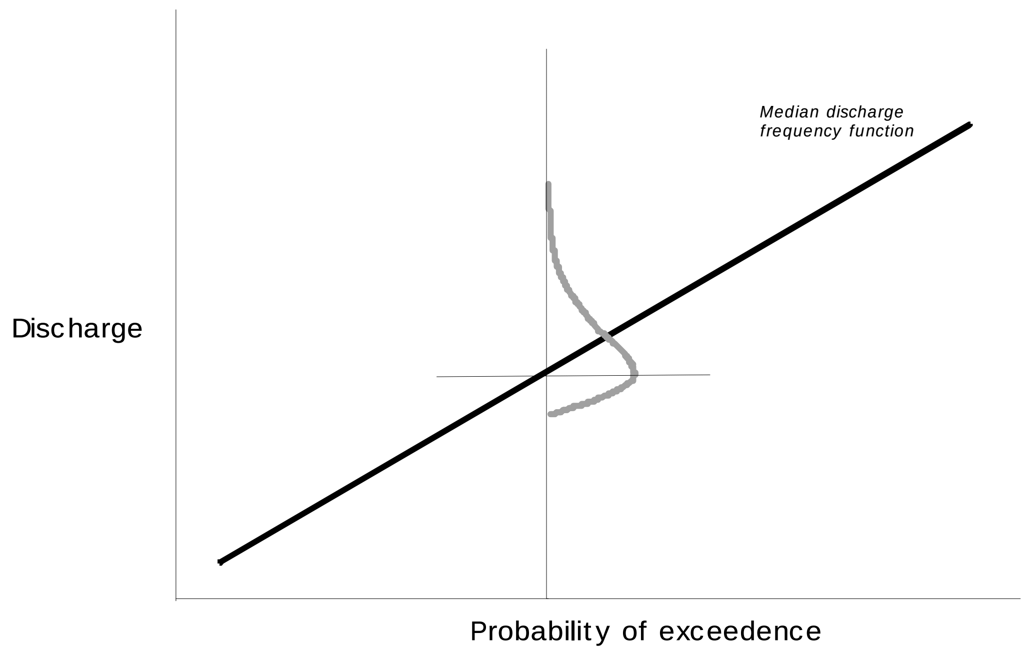

Figure 12. Illustration of probability distribution of errors in discharge-frequency function

The procedure for accounting for the effect of uncertainty in the hydrologic, hydraulic, economic, and geotechnical conditions is relatively simple: We sample the functions that describe the uncertainties as we compute the indices, presuming that errors in the estimates are random errors (and not blunders).

The flowchart that is included as Figure 13 shows the steps in this computation as it is carried out in the Corps' HEC-FDA computer program. As that program synthesizes a long record of annual maximum flow data, it samples also the function that describes error in predicting flow for a given probability. The prediction error is added to the synthesized flow. As the flow is transformed to channel stage, the random error in predicting the corresponding stage is sampled and added in a similar manner. Likewise, the error in predicting levee performance and the error in predicting damage for a given stage in the floodplain are sampled and incorporated in the analysis.

Additional details are provided in the HEC-FDA program user's manual.

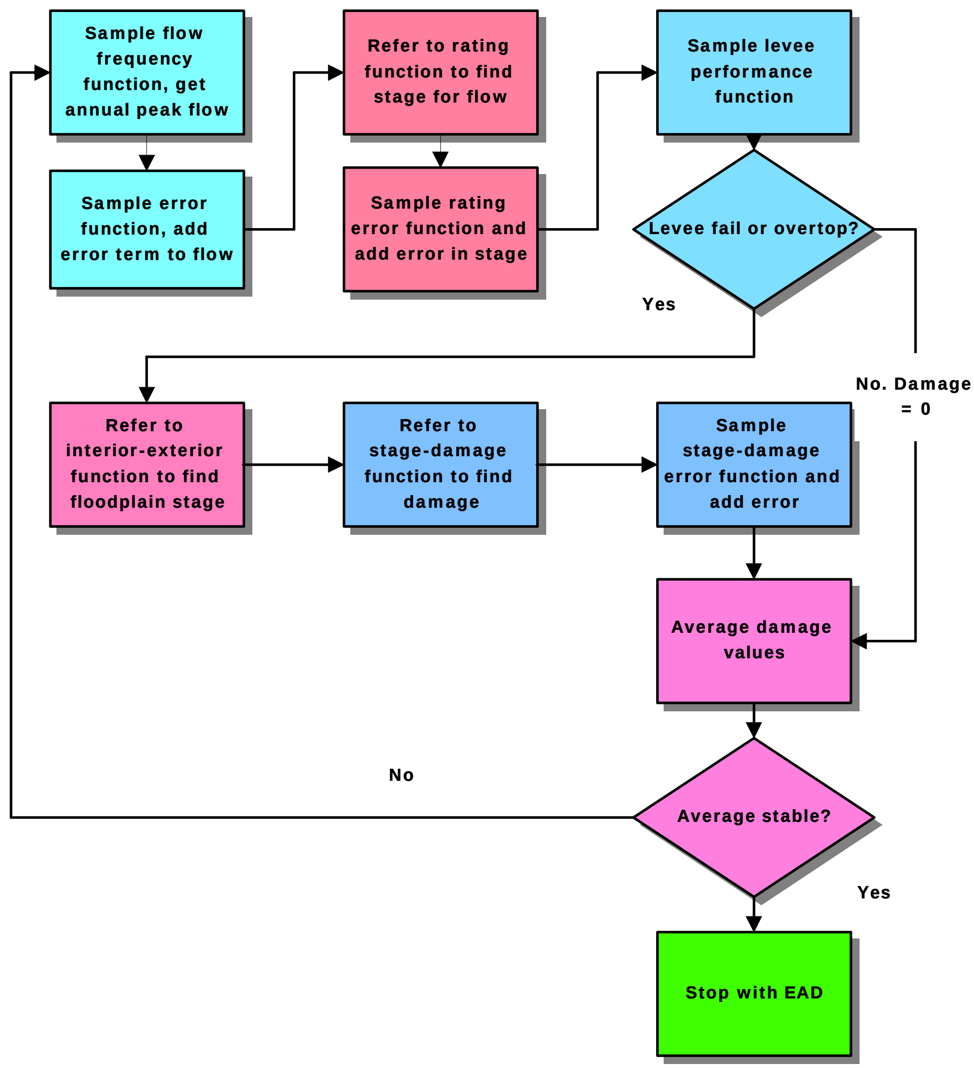

Figure 13. Steps of EAD computation with sampling

Appendix V. Notes from stakeholder interviews

To identify the options described in this report, we solicited input from experts who are knowledgeable of flood management issues and of possible solutions to the problems of measuring and preventing or mitigating adverse impacts of system improvements. This appendix includes notes from interviews, along with other information provided by the stakeholders. In the text that follows, we use italics to denote quotes from the interviewees or material directly from e-mail from the interviewees.

Comments from Fran Borcalli, PE

Mr. Borcalli of Wood Rodgers, Inc., Sacramento, reviewed material from an initial draft of this document and offered the following comments on December 4, 2006:

Common models

If an impact index (or a set of indices) is to be used in an equitable manner, a common set of hydrologic, hydraulic, geotechnical, and economic data and models must be developed and made available to analysts, including applicants and Board staff. The Corps' Comprehensive Study models and data are a good start. Recent work by DWR, the Corps, reclamation districts, and river authorities to enhance those models should be incorporated in a common, shared analysis toolkit. The models and data can then be shared in the future among applicants, with the understanding and requirement that each provide any new data or model improvements that result from their studies.

California DWR is the likely candidate for librarian for these models and data. Beyond distribution, DWR staff can review and control modifications to the models and data. A funding mechanism must be established for this.

Land use considerations

While, strictly speaking, the mission of the Reclamation Board is not land-use planning, addressing hydraulic impacts and mitigation requires consideration of land use in the Central Valley.

Indices and strategies for mitigation should be selected so that they do not penalize communities for slow growth. For example, Yolo County has not developed rapidly in some areas that are protected by levees, electing instead to leave land in agricultural uses for the present. However, Sacramento County has converted agricultural land to residential at a faster pace, and thus requires enhanced flood protection. Approved improvements for Sacramento should not put Yolo in a position that it cannot transform property to higher-valued use in the future.

Cost-benefit requirements

If mitigating adverse impacts of improvement requires construction or compensation for potential or actual damage, a benefit-cost analysis should be completed. The analysis should lead to determination of a reasonable limit on the cost of the construction or compensation.

Comments from Stein Buer, PE; Tim Washburn; Pete Ghelfi, PE

On November 21, 2006, Mr. Buer, Mr. Washburn, and Mr. Ghelfi of the Sacramento Area Flood Control Agency (SAFCA) offered the following comments on selection of impact indices and mitigation options:

- A common set of hydrologic, hydraulic, geotechnical, and economic data and models must be developed and made available to analysts if the analysis is to be uniform. California DWR can maintain this set of models and data. A funding mechanism must be established for this.
- The baseline for computation of any index should be established carefully and clearly. Should the standard for comparison and computation of the index be the original 1957 design? Should it be the 1957 design, as modified by current reservoir flood operations that have been approved by the Corps of Engineers? Should it be the current, without-improvement condition?
- The standard for and measure of levee reliability must be carefully determined and clearly articulated, so that when legal challenges arise, the plan for maintaining levees can be explained and understood by the public and the courts. If the design standard does not mean elimination of all risk, then that should be clear.
- It may be appropriate for the Board to establish and apply different indices or standards for (a) rural, (b) dense urban, and (c) small communities with lower density. The metric for differentiating these would be population density. A different cost limit would be established for mitigation for each category.

Washburn provided a detailed analysis prepared by SAFCA of various hydraulic mitigation policies. This is included herein as Table 8.

Table 8. Comparison of hydraulic mitigation policies (SAFCA 2006)

Policy (1)	**Application (2)**	**Strengths (3)**	**Weaknesses (4)**
Federal - Levee improvements that could result in an increase in flood inundation levels on lands outside the protected area do not warrant hydraulic mitigation unless the increased flood levels would occur on a frequent basis in a manner that would frustrate the landowner's reasonable use of the affected property[1].	*This policy was applied by the Reclamation Board acting as the non-federal sponsor of the West Sacramento Levee Improvement Project. The SRFCP levees along the south side of the Sacramento Bypass and the east side of the Yolo Bypass were raised to provide optimal protection to the City of West Sacramento. Small increases in water levels outside the protected area for the rare floods contained by the project were not considered subject to mitigation.*	*This policy reflects the federal approach to inverse condemnation. It thus provides a framework for interpreting the assurances that the state has provided in connection with the SRFCP. This policy is appealing because it allows a balancing of the relatively substantial flood damage reduction benefits that can be achieved through raising urban levees against the relatively insubstantial consequences of increasing flood depths on agricultural lands in very rare floods.*	*This policy may be viewed as unfair by agricultural interests and, although California's judicial approach to inverse condemnation is similar to the federal approach (state plan of flood protection may not impose an unreasonable risk of harm on a protected property owner, thus compelling the property owner to contribute a disproportionate share of the cost of the project), after Paterno, some argue that state courts may be more protective of property owners claiming harm caused, at least in part, by redirected flood waters.*
"True Exceedence" – Levee improvements that could result in an increase in flood risk (as measured by expected damage) on lands outside the protected area may be mitigated by increasing upstream reservoir storage or taking other steps that benefit the affected lands and avoid an increase in expected damage.	*This policy was applied by the Reclamation Board in issuing a permit for SAFCA's North Area Local Project. The SRFCP levees along the Natomas East Main Drainage Canal and its tributaries east of Natomas were raised to provide "200-year" protection to Natomas and North Sacramento. Small increases in water levels outside the protected area for the rare floods contained by the project were considered adequately mitigated by Folsom Reoperation.*	*This policy is appealing because it offers a pathway for developing a comprehensive approach to improving SRFCP system performance that would yield benefits to urban and rural areas. Urban levee raises could be combined with improvements in reservoir operations, better maintenance of rural levees, and other measures that would tend to reduce expected damages in rural areas.*	*The technical tools and skills needed to apply this policy on a systematic basis do not exist. Therefore, a precise, project-by-project accounting for expected damage increases and reductions affecting the SRFCP would not be possible. However, a general accounting that anticipates a 10- or 20-year program of SRFCP improvements might address the perceived inequities of the federal policy discussed above.*

Policy (1)	Application (2)	Strengths (3)	Weaknesses (4)
<u>Flood Insurance</u> - Levee improvements that could result in an increase in flood inundation levels on lands outside the protected area may be mitigated by insuring the residential structures occupying the affected lands.	*This policy was applied by the Reclamation Board in connection with the South Sacramento Streams Group Project. The SRFCP levees along the northern end of the Beach/Stone Lake floodplain were raised to provide at least a "100-year" level of protection to portions of the City of Sacramento. Small increases in water levels on lands in this floodplain outside the protected area for the rare floods contained by the project were considered adequately mitigated through creation of funds to cover the cost of insuring the residential structures on the affected lands.*	*This policy is appealing because it addresses in a potentially cost-effective way the relatively small economic effects for which other structural mitigation measures may be considered infeasible. Such a program would have to be administered by the State of California, perhaps through creating an income tax credit for qualifying rural residents in SRFCP protected floodplains.*	*An effective flood insurance program for rural areas would be difficult to administer and could be costly to the state. To control costs, the state could limit the program to rural residential structures only, and limit the amount of any tax credit through a cap on the creditable portion of the premium. Since qualifying residents would likely be in newly mapped 100-year floodplains, the program could reduce its costs by encouraging participants to obtain NFIP insurance at current rates before the new maps are effective.*
<u>Levee Parity</u> – Projects involving levee improvements that could result in an increase in flood inundation levels on developed residential lands outside the protected area must include levee improvements that provide equal protection to the affected residential lands.	*This policy was applied by the Reclamation Board in permitting the later phases of SAFCA's NALP in the lower Dry/Robla Creek floodplain. The SRFCP levees along the south side of Dry/Robla Creek were raised and a new SRFCP levee was constructed along the north side of the Creek to provide portions of North Sacramento with a "200-year" level of flood protection. SAFCA was required to mitigate small increases in water levels on developed residential areas along the fringe of the Dry/Robla Creek floodplain by constructing a new levee and related drainage improvements around the affected residential*	*This policy is appealing if "developed residential lands" could be defined to focus on the small communities in SRFCP protected floodplains based on appropriate size and density criteria. The state plan of flood protection could designate these areas for protection, either through structure elevation or through levee improvements, with a spending cap of up to $25 million per project. Since such a spending cap could require a limited improved levee perimeter, the small community would need to take responsibility for identifying this perimeter in order to qualify for funding.*	*This policy would need to be part of the larger state plan of flood protection. Small community levee parity projects could be very expensive if eligibility criteria are too broadly defined. Reaching agreement on confined protection boundaries has not been easy in areas where this has been attempted.*

Policy (1)	Application (2)	Strengths (3)	Weaknesses (4)
	areas.		
Levee Strengthening - Projects involving levee improvements that could result in an increase in flood inundation levels on lands outside the protected area need not include hydraulic mitigation if the levee improvements are limited to strengthening or raising the affected levees within the minimum freeboard requirements designated by the SRFCP (1957 profile).	*This policy guided the levee reconstruction program, including the Sacramento Urban Levee Reconstruction Project, that was implemented in the aftermath of the 1986 flood.*	*This is an appealing policy because it is simple to understand and administer.*	*By itself, this policy is insufficient to guide the state plan of flood protection or address the pressing need to implement urban area improvements as quickly as possible. This policy should be the minimum basis for exercising state oversight of the SRFCP, not a substitute for developing the complementary policies that would allow the state to fully address its flood control and flood risk management needs.*
Federal Modified – Urban area improvements, including levee raises, may be implemented without hydraulic mitigation as long as such improvements do not cause encroachments into SRFCP design levee freeboard for rural levees (1957 profile) or urban levees (100-year and "200-year" profiles).	*This policy is described in SAFCA's recently issued Program EIR for Creating New Funding Mechanisms. Using this policy to guide its hydrology and hydraulics impacts analysis, SAFCA has concluded that its proposed program of levee raising and strengthening, and Folsom Dam and Reservoir physical and operational improvements can be implemented without resulting in significant adverse impacts to the SRFCP.*	*This policy is appealing because it would allow urban area improvement projects to proceed on an incremental basis pending agreement on a comprehensive state plan incorporating the measures described above. This policy references the standards likely to be incorporated in the state plan, including standards for urban levees that assume rural levees overtop without failing. This leaves room for the state plan to take shape without having to delay needed urban area improvements.*	*Rural areas may feel that this policy is insufficiently protective and may be reluctant to allow it to guide early start urban area improvement projects in the absence of a more fully developed (and funded) state plan.*

Notes:

1. Under applicable federal law, compensation is required when an individual property owner is compelled by government action to bear public burdens which, in all fairness and justice, should be borne by the public as a whole based on (1) the character of the governmental action, (2) the economic impact of the action as applied to the particular property, (3) the property owner's distinct investment backed expectations with respect to that property.

Comments from Joe Countryman, PE

Mr. Countryman of MBK Engineers, Sacramento, offered these comments by e-mail on October 13, 2006.

I am very concerned that some at the state are contemplating using R&U for this purpose [impact analysis].

I can not think of a worse tool. The necessity for assuming values like PNP and PFP and utilizing pdfs that go beyond any reasonable extrapolation to decide if there is a need for hydraulic mitigation seems to be insanity.

An Example, we have a levee that has a foundation sample that indicates it does not meet current Corps seepage criteria. Someone decides that in order to meet the new seepage criteria the water level needs to be 10 feet below top of the levee (PNP). The levee was initially designed to protect against a flood that had 3 feet of freeboard and that for uncertainties in stage, etc had a reasonable chance of not failing until overtopped (50%).

How does changing the PNP and PFP at this site affect any other site? The stage frequency curves are not changed are they? I've recommended using levee failure with overtopping in developing the stage frequency curves. Then apply that before and after. In this case if a levee were raised or setback a different stage frequency curve would be developed. And that would allow analysis elsewhere in the system.

But why do a damage calculation? In nearly all situations the original project water surface profile remains unchanged. Does it make any difference that the water surface elevation changes 0.2' at the 200-year level if the project was designed to pass the 50-year flood. Why would hydraulic mitigation be called for under this condition?

Mr. Countryman offered these additional comments by e-mail on November 1, 2006.

Does a levee failure result in reduced peak flood stages downstream?

On the Sacramento River system, the answer is maybe. The 1986 and 1997 levee failures on the Yuba, Feather and Sutter By-pass did not lower peak flood stages downstream. 1986 levee break occurred well after the peak and the 1997 flood occurred at the peak.

If a failure occurs well before the peak then the opportunity to have flood relief downstream is at the greatest.

What should be assumed as a levee failure criterion for hydraulic modeling?

This is an extremely complex question. History provides examples of levees not failing when overtopped, failing when overtopped, failing when encroached in the freeboard, failure below the freeboard.

In order to perform an impact analysis a consistent assumption is probably required.

Assumptions based on a water level below the top of the levee require failure criteria for the levee that could indicate levee improvements to meet a basic levee maintenance standard could trigger a hydraulic impact. The most obvious scenarios are slurry walls and bank protection.

A Risk & Uncertainty approach to levee failure is complicated because sometimes the levee will fail at a certain water surface elevation and other times it will not. The timing of the failure is not addressed (before or after or during the peak). Uncertainty in the failure mechanism disconnects the direct impact downstream because the stage frequency curve is an unknown at the downstream points. This may be realistic but it makes a hydraulic impact analysis nearly impossible.

What are downstream areas entitled to expect as far as upstream flooding?

The Corps performs a taking analysis. Here the question is "Does the project adversely affect the value of downstream property?" I am not aware of the Corps making a taking finding on any project. If levees exist at the downstream location, upstream work does not affect the levee design condition (normally) downstream. Therefore levee failure downstream will be unaffected by upstream improvements as long as existing upstream and downstream levels of protection are similar. (if the downstream levee overtops with the 100-year flood it will still overtop with the 100-year flood even if the upstream levee is improved to 200-year)

The SRFCP established design flows and design profiles. This is what anyone protected by a project levee can assume is their "level of protection". The courts have found that inverse liability does not carry over for floods that exceed design.

When the Corps evaluates proposed projects that may modify the flood control system, they evaluate the design flow. Will the project be able to contain the design flow within the prescribed design stage? Also does the project adversely affect downstream conditions for the design flow? The San Joaquin River levees were designed for a 50-year flood. There is a presumption that the levees have a high probability of failure when flows exceed the design flow. If Stockton was provided 200-year protection, how would that affect the 50-year protection designed for their rural neighbors?

My engineer understanding of Paterno is: The state is responsible because the project features did not meet the standard of care criteria to pass the design flow. If the flows had exceeded design and the levee failed there would not have been a finding of Inverse.

There are significant disparities in top of levee elevation in the SRFCP.

If it is the State responsibility to assure that everyone in the system has the same design flood capability (both sides of the river are required to have the same freeboard for the design flow), does the State have the responsibility to degrade levees that are higher than the design profile?

The flood system was designed to meet minimum standards. 20' top width, 1:3 1:2 etc. To my knowledge exceeding these minimums has been encouraged in the past. Would this now result in "hydraulic impacts" because the probability of flooding has been reduced?

The design flow and design water surface elevations were established before the construction of the reservoirs.

Has the state gained a credit against any perceived hydraulic mitigation requirement because of the reservoir constructed upstream? Folsom Oroville and New Bullards Bar have certainly provided a benefit to downstream areas?

Does "The Project" include all of the flood control features? If so, everyone has gotten better and modifications to the project (raise a levee) does not change that.

Should we use an economic model to calculate impacts and mitigation?

Would such a procedure preclude an upstream city from receiving flood protection but allow the downstream city to receive the protection because there was no urbanization downstream?

As will all computer models, if you change inputs the model will calculate a change in damages. Does this make the damages real?

The fact the Corps Authorizes a project does not eliminate potential State liability.

It has been stated by some that if the raising of the levee was authorized by the Corps then State liability is not an issue.

Since the SRFCP is an authorized project and State liability has been established, the premise seems to be erroneous. Why, because the State holds the Corps harmless for whatever liability exists because of the project.

Comments from Butch Hodgkins, PE

Mr. Hodgkins of the California State Reclamation Board provided the following comments via e-mail on November 30, 2006.

My biggest concern is the technical approach to any of the frequency or damage indices. The biggest question is how you establish preproject frequencies when we know the entire system is suspect. While I kind of like just saying it fails at the design profile, I can not square that with my feeling that history does not support that assumption. Can analysis be run that *reflect the results of the change in failure points without establishing what the failure points are? I can't see how, but there is much more that I do not understand than I do understand. I hope you have an easy answer to this question, as the rest of this seems like the emperor's clothes.*

Improvements considered

It seems to me this should also include changes in system operation. If we get a preferred approach out of this, we also should follow it when we deal with issues like re-op and new or modified pump stations?

Legal issues

...I know the attorneys will look at the law. However, I think the engineers have to look as well so that we can demonstrate to the attorneys and the judges that we tried to use their criteria. I fill confident that you know the test that the Courts have applied in inverse cases, mostly after flooding has occurred, but it is the reasonableness test for inverse. It is part of the reason I am so focused on AAD.

Proposed indices

[Hodgkins provided the following comments on the indices proposed]:

1. Increase in water-surface elevation for system design flow (the oft-cited 1957 profile). *Good*

2. Increase in water-surface elevation for flow of specified annual exceedence probability. *Good*

3. Increase in potential damage for system design flow. *Good*

4. Increase in potential damage for flow of specified annual exceedence probability. *Good*

5. Increase in expected annual damage (EAD). *Good*

6. Increase in average damage due to flows greater than system design flow. *...Is there a stage change for the design flow, or does it mean flow above system design?*

7. Increase in annual probability of inundation (residual risk) in interior floodplain. *Need a strong definition of residual risk.*

8. Decrease in probability of safely passing design flow.

9. Decrease in probability of safely passing flow of specified probability.

How about combining some form of change in damages index with a change in frequency index? I think just dealing with frequency makes it politically very difficult to deal with these issues. When I said damages at our meeting, you called it an economic impact. While that is certainly true, to me it is likely to provide a more meaningful understanding of what a change in frequency really means.

By the way, the information that I think is important is the answers to the following questions:

- *Is more property inundated? How much more?*
- *Are flood depths deeper? How much deeper and what are the implications of the increased depth with respect to risk to public safety and economic damages.*
- *Are more structures flooded? How many more and to what depth?*
- *Is the reconstruction cost increased and by how much. 5% or 50%.*
- *Are there measures that could be constructed that would cost effectively reduce damages. For instances, spillways that prevent levee damage and/or outlet structures to aide in draining an area once it is flooded. Interior levees to prevent widespread shallow flooding. Anything?*

If one could assume the levee fails at the '57 design, then changes above the design frequency probably mean more water, not more frequent flooding. The question that I think is important is does more water mean more damages, and how much more. I do not have any idea what such an analysis will show, but I think it's the right question if an analysis can be done that is a reasonable indicator of reality. [Some say that] *the Corps method* [is deficient]. *...I do not want to end up with an index that is not determinable or is a meaningless number.*

Mitigation options

[Hodgkins provided the following comments on the mitigation options proposed]:

4. Insure those with increased damage potential. *How about just pay the damages?*

5. Collect impact fee to offset increased construction cost for system-wide plan of flood control. *This is only feasible as something like a 100-year program... There are 1600 miles of project levees. At 5 million a mile that's 8 billion, without anything for the delta and non-project levees. Besides, after you look at* [Table 3] *you will see that system design poses an even greater problem.*

Summary

Q: Have we omitted any indices that you think critical? Included any that you think inappropriate or just plain dumb? Do you think one of those listed is superior? Why?

A: *I will reserve forming an opinion about the best index until I have the benefit of your analysis.*

Q: Have we omitted any mitigation options that you think critical? Do you think one of those listed is superior? Why?

A: *Insurance could include a subsidy either in the form of a tax credit or cash payments. However insurance doesn't pay the cost of reconstructing the levees and regarding the interior fields. Perhaps there could be a fund created that provides cost sharing for damage repair.*

In some cases, purchase of easements may be appropriate, but I suppose that's part of reimbursement.

Comments from Chris Neudeck, PE

Mr. Neudeck of Kjeldsen, Sinnock and Neudeck, Stockton, provided the following comments from Nomellini, Grilli, and McDaniel, a professional law corporation in Stockton, CA.

The concern for impact on design flow, as well as flows greater than current design flow appears to be covered. There are of course adverse impacts at lower flow levels and from increased duration of peak as well as other high level flows.

When conditions are at or above warning stage, the objective should be to avoid increases in water surface elevation as well as increases in the duration of the high flows. The indices might cover this concern however, Indice 2. could be changed to read "Increase in water-surface elevation and/or duration of flow during periods when river water levels are above warning stage."

Impacts associated with routing of floodwaters and/or raising the depth of floodwater in flooded areas is a concern.

Along the rivers where there is a significant gradient in the floodflows, relief cuts are essential to avoid the lev of a flooded district which are downstream of a levee break from acting as a dam. The higher the levee the greater the depth in the flooded area and in many cases the greater the extent of the area flooded. I would suggest additional indices as follows:

"Indice 10 - Increase in depth of floodwaters in the event of levee failure or failures in the vicinity."

"Indice 11 - Increased potential for extending the flooded area."

As a general proposition, so long as elevations are lower than those for urban development, the raising and strengthening of existing levees which have been part of longstanding reclamation plans or flood control projects (unless restricted by elevation control easements) should be viewed differently from levee relocations and construction of new levees. For the historical levees along the rivers, provisions for relief cuts should resolve the problems.

When the raising and strengthening of existing levee systems protecting agricultural areas approaches or exceeds the criteria for urban development, there could be a significant shift of flood impact on already developed areas which should be considered. There are obvious inequities in restricting the land use of one party to benefit others who have developed more rapidly and hopefully more flood control planning and acquisition of flowage easements can address this issue on a broader basis.

Neudeck also provided the following comments from Mr. Alex Hildebrand.

I believe the "indices" should move levee improvements toward a more uniform level of protection for rural lands, and better protection for urban lands. There is so much interdependency among protection of adjacent districts that it can be futile to increase the ability of a district's levees to withstand a flood stage above the standard for rural levees if failure of a nearby district's substandard levee will flood the first district even if its levee is improved.

On the other hand, I believe every district has a right to improve its levees. Consequently, no district should rely on reductions in flood stage due to failure of other districts' levees. If urban levees are built to withstand a higher flood stage than the rural standard flood stage, the rural levees will break first. However, the urban districts must not acquire a right to prevent the improvement of other districts' levees. These districts may later become urban districts, or the protection of public infrastructure or water quality protection may justify raising the standard of those levees.

The basic network of channels and lands in the Delta must be maintained in order to protect the public infrastructure in the Delta, and the public's need for exports, and the recreational and environmental and agricultural benefits. There must not be confusion between the urgency in improving and repairing urban levees, and the need over time to protect the entire Delta and avoid its becoming an inland sea.

The "indices" should be compatible with the above considerations. In the case of South Delta levees, they were intended to be adequate after they were raised in the 1960s to convey 52,000 cfs from Vernalis to the central Delta without levee breaks. However, the levee cross sections, the levee and subsurface materials, and the lack of bank protection and of channel and bypass maintenance have resulted in an inability to carry that flow.

1. Levee improvements, channel restorations, and other measures to safely convey 52,000 cfs from Vernalis should be encouraged.

2. Measures that would decrease flood stage with 52,000 cfs at Vernalis should be encouraged. These include increasing the flow capacity through and downstream of Paradise Cut and through Middle River by measures that do not increase flood stage in those channels and which would decrease flood *stage elsewhere by increasing the overall conveyance capacity through the South Delta.*

3. Measures that would reduce channel flow capacity or otherwise increase flood stage at design flow should not be allowed.

I recognize that there are regulatory requirements that hinge on whether an urban levee is believed to be able to have no more than a one percent chance of failure each year. In principle this is a worthy but inadequate goal that will result in some levee improvement. However, it ignores the extent to which flood stage is influenced other than by levees. Furthermore, there is no way to determine with confidence what flood event has this frequency of occurrence. That depends in large part on what measures are pursued upstream to minimize brief peak flows. Its determination also involves substantial extrapolation of a short record of flood events.

Comments from David Peterson, PE

Mr. Peterson of Peterson, Brustad, and Pivetti, Inc., Folsom, offered these comments by e-mail on December 1, 2006.

Hydraulic Impact Indices

1. Strengthening*. Levees were constructed to hold water. That was the intent at construction. Therefore, measures to strengthen levees do not constitute hydraulic impacts. This should be a categorical exemption.*

2. Hydraulic cross section modifications*. Any proposed change to the hydraulic cross section must be analyzed for hydraulic impacts to others. Hydraulic impacts include increased water surface elevations, or increased velocities. Levees should be designed for continuous exposure to the design condition, so increased duration of exposure should not be considered a hydraulic impact. Pre-setting quantitative thresholds for impacts is unwise. Project proponents should be required to reveal the project impacts, and then mitigate them to less than significant.*

3. Hydrologic modifications*. Any proposed changes to the land or waterways that would alter the flood hydrographs must be analyzed for impacts to others. Pre-setting quantitative thresholds for impacts is unwise. Project proponents should be required to reveal the project impacts, and then mitigate them to less than significant.*

Analysis Techniques

1. Hydraulic impact analysis*. HEC-RAS of pre- and post-project conditions for all flood frequencies found in most FEMA flood studies. Many projects have "break points" in hydraulic response, so it is important to analyze a range of flows.*

2. Hydrologic impact analysis*. HEC-HMS or HEC-RAS unsteady of pre- and post-project conditions for the range of flood flow frequencies described* *above. Hydrologic analysis should extend downstream of the project in order to determine if changes to lag time will increase flood peaks downstream.*

Mitigation Techniques

***1. Hydraulic impacts**.*

***a. Increased water surface elevation**. Either raise levees upstream until the impact is less than +0.05', modify the cross section to lower the water surface to pre-project conditions, or provide compensated relief zones in adjacent floodplains. Dredging below the thalweg should not be included in the toolbox, as it only induces sedimentation.*

***b. Increased velocity**. If raised velocities are high enough to be erosive, either provide erosion protection in the affected area, or modify the cross section to keep velocities at or below pre-project conditions (excluding dredging below the thalweg).*

***2. Hydrologic impacts**.*

***a. Increased peak flood magnitudes**. Provide mitigation for 1a hydraulic impact or flood detention upstream. If adjacent floodplains are to be used for relief zones, appropriate landowner compensation must be provided, and permanent flood easements secured on behalf of the State.*

***b. Delayed or advanced flood peaks**. If delaying or advancing the flood hydrograph has the effect of increasing flood peaks somewhere downstream, utilize detention to correct the timing of runoff to pre-project conditions, or to a more advantageous regime.*

Comments from Pete Rabbon, PE

Mr. Rabbon of DWR (currently on assignment to the US Army Corps of Engineers, Institute for Water Resources) offered these comments during a phone interview on December 6, 2006.

Impact indices

***1. Board's responsibility**. The board is in a position of policy making, not index measuring and enforcing. They are responsible for public safety behind the levees. The bigger picture, the global index, is public safety. For compliance with technical issues relating to levees, applications submitted to the Board must be compared to adopted technical indices by the Chief Engineer on staff to the Board. The Chief Engineer would then report to the Board on whether the project addresses the indices adequately.*

***2. A full suite of indices needed**. There will not be one index that will adequately address every project submitted. The Board, with the recommendation of the Chief Engineer, shall choose the index, from the adopted set of indices, that best represents each unique situation. The applicant should present their general concept plan, in the early planning* *stages, to the Board with enough detail so that an appropriate index can be chosen and agreed to for full analysis.*

***3. The system design event as an index**. While the system design (1957 profile) is a good base to compare against, any freeboard associated with this level is absolutely necessary and encroachments into, whichever is less, the design freeboard or actual freeboard at design flow should not be allowed.*

***4. Levee strengthening – what's the index?** If two stakeholders are across the river from each other, or stakeholder #1 is immediately downstream from stakeholder #2, would stakeholder #1 be impacted if stakeholder #2 strengthens their levee? Yes, stakeholder #1 will now have a higher risk. How to measure this risk is unclear. Some negotiating mechanism needs to be in place when this occurs. The availability and applicability of analysis tools for this is a concern.*

Mitigation

***1. Mitigation needs to match impact**. If there is a permanent impact due to the construction of a project, the mitigation for that impact must be permanent also. Or, an interim mitigation must have a clearly defined schedule and funding mechanism until the permanent solution is realized. This highlights the need for a state plan of flood control, with a rational and stable funding mechanism. The 70 years required to build the current Federally authorized project on the Sacramento River lead to allowing temporary mitigation measures that in reality should be considered and managed as permanent mitigation measures.*

Comments from Jeff Mount, PhD

Prof. Mount of the University of California, Davis, offered the following comments by e-mail on December 5, 2006:

***Rational List**: your charge is to produce a rational, practical list. In that regard, you may want to simplify this a great deal. The longer the list, the more quibbling you are likely to get. A long list may have the unwanted consequence of limiting Board flexibility in interpreting their mandate. The last thing you (or they) want to have happen is that their decisions be handcuffed by adhering to a checklist. Engineers might like protocols and checklists, but having been on the policy end, you welcome flexibility in interpretation. In addition, the presence of a list like this makes it difficult to consider issues that may land outside of the list, and open them up for criticism, if not lawsuits, from applicants who will view the decisions as arbitrary. Worse yet, you may get a range of applicants who develop clever work-arounds (I can see them already) in order to present their projects in the best light according to "the list." Frankly, I would advise the board to set a clear policy and then decide these issues on a case-by-case basis. This list will work its way into a formula, which will work its way into distorted policy,* *etc. That said, you have been asked to make a rational list by the board, but I bet they haven't thought through the consequences yet…*

Initial List of Indices*: this strikes me as a pretty comprehensive list, most of which are clearly autocorrelated. That is, if you get a positive hit on one, you are likely to get a hit on all the rest. So for that reason, why not simply make a policy of no net increase in EAD or Residual Risk, with preference given to projects that reduce these. This places a big burden on the applicants, I realize, and falls into the "cumulative effects" black hole, but it would be the most effective approach and offer the Board a great deal of leeway. Too bad the Comp Study wasn't completed. It would be a useful tool for this.*

Another comment is the term "Decrease" and "Increase". Do you want to offer some specificity in this regard? That is, what constitutes a significant change? Is it when the historical .01 exceedence probability event moves to .02? Is it when the change exceeds the error in the model? When stage rises 6"? Or? The Board always hears comments from consultants and staff about "no significant change", but frankly, I have never heard a discussion about significance.

Yet another comment is what to do about duration. I can easily envision that a project will not impact stage, but may have the effect of increasing the duration of high stage during large flow events (dam releases are the best example, of course). Since it is duration of high stage that is the ultimate levee killer (with the exception of overtopping, I guess), how do you capture this metric?

Finally, and this is the 800 lb gorilla in flood management in the Central Valley, [some applicants]… *will protest that as long as their project is not increasing stage anywhere, it is having no impact and should be permitted. I don't buy this, as you know for two reasons.*

First, any project that modifies levees and/or the activities behind them changes the plan of flood control. That is, there are now new urban areas that need to be protected by the flood control system that were not there prior to the project. This increases the likelihood that mitigation in order to protect this and other future projects will have to be accommodated elsewhere in the system in the future. It is a deferred cost, rarely considered.

Second, not increasing stage is only one aspect of the project. If, historically, that project's levee failed (or could have failed) and accommodated flow during events that exceeded design capacity, then by upgrading that levee you have transferred catastrophic storage potential to another part of the system.

[Two recently proposed improvements] *are classic examples of this. Levee "arms races" are not just about increasing stage, but managing floods that exceed design capacity of the channel, since failure is not uniform everywhere, and benefit is accrued throughout the system. I know, these two* *issues are politically and legally dicey and involve some circular reasoning, but they strike me as pretty darn important as we head out to upgrade our existing levee system. I suppose they could be embedded into the EAD or Residual Risk equation.*

The list of mitigation options seems fine to me. You could collect an impact fee that also funds the reimbursement for increased damage potential (something Sacramento should be doing, I suppose). I have no idea how feasible any of this is.

Comments from Mike Hardesty

Mr. Hardesty (President of Central Valley Flood Control Association and General Manager of RD 2068) offered these comments during an interview at his office on December 12, 2006.

Before getting into the specifics of indices and mitigation, a general discussion of floodplain management within the state is needed. What is the State flood control plan? Flooding issues are a complex, system-wide issue and need to be addressed as such. There should be one system project and one overall economic analysis.

Impact indices

1. Basis of comparison. The 1957 system design (profile and cross-section) and flows need to be the baseline of comparison when looking at impacts to the system. This is the accepted design established by the Corp of Engineers and is what the system was designed to accommodate. The difficulty in using an annual exceedence probability is that it is a moving target – not a concrete, reliable indicator.

2. Cumulative impacts needed. Need to determine the cumulative impacts of the projects combined in the whole system, not just looking at single project impacts in immediately adjacent or immediately downstream properties. For example, maybe one project only raises the water surface at the index point by a few hundredths of a foot. This might be considered no impact. But what if there are five other projects upstream that also raise the water surface by the same incremental amount. The cumulative effect will have an impact. This has to facilitate a new commitment to the long-term sustainability of the "system" where each component or region gets some reliability in the level of protection provided by the "system."

3. Using expected annual damage (EAD) as an index. There are problems with using this as an index in such that there is not an industry-wide understanding or confidence in the calculation. There is also the problem that agricultural land will never "rate" on the same scale as urban when looking at damages incurred by inundation. This is especially important if the USACE's current method of incremental economic analysis is applied. This allows damages to be hydraulically relocated throughout the system, yet costs of addressing these damages are constrained locally by either jurisdictional or hydraulically contiguous regions.

4. Damage from flows greater than the system design flow. Most damage to levees comes from the more common events. Erosion damage comes from the 10, 15, and 25-year events. Looking only at damage from flows greater that the system design minimizes, or worse marginalizes, the impacts of structural damage to levees from smaller events.

5. Failure of upstream or adjacent levees boosting protection. The State should have a standard of *not* relying on failure in the system, at an upstream or adjacent location, to increase the level of protection to the property in question. For example, the level of protection provided by the levee protecting property B should not be dependent on failure of the levee protecting property A, located upstream. On-the-other-hand, regions should not be able to relocate damages to other areas without some kind of mitigation, see 1, 2 & 3 below.

6. Should be a matrix of indices. Some of these indices build upon the previous. Such as index #3, increase in potential damage for system design flow, is reliant upon the calculation necessary for index #1, increase in water-surface elevation for system design flow. There is not just one index that addresses all concerns.

Mitigation

1. All mitigation listed should be considered. All of the mitigation options listed could be implemented every time an impact is realized. The Reclamation Board is duty bound to notify anyone who is adversely impacted. Collection of an impact fee to offset increased construction cost for the system-wide plan of flood control is absolutely needed. Fees do not have to be local, but the point is that impacts to the system design and performance need to be accounted for, and a reliable revenue stream needs to exist to provide for repair, reconstruction and maintenance. There are both local and statewide benefits derived from the flood control system, it is logical to assume there would be a variety of revenue sources, local through statewide. Those seeking enhanced local flood control benefits (improvements) would need to bear an enhanced financial burden to develop and sustain those improvements over the long-term.

2. Best mitigation is prevention. The #1 mitigation listed should be "no impact". Projects should provide designs, if feasible, that do not impact the system.

3. Other types of "insurance." Although standard flood insurance should be offered to those with flood damage potential, other types of insurance should be considered. What about the lease of land up or downstream that would provide the capacity, conveyance or storage, needed to reduce localized impacts?

Further discussion

1. More than one standard. When analyzing projects against a matrix of indices and mitigations, there *may* need to be more than one standard. There could be a set of standards for rural properties and a set of standards for urban properties. I prefer to see this as a gradation of the base condition. The universal base condition is the “1957 design.” For small town and rural population centers, an enhanced suburban levee standard could be developed, then for large urban populations a highly protective standard would be used.

This would be an attempt to address both the economic capacity of varying populations to support flood control solutions as well as recognizing the value of protecting increasing densities of high value property and infrastructure behind levees.

2. Acceptable base condition. Need to establish an acceptable base condition to compare projects against. The current condition of a levee is often not acceptable for a base condition.

Comments from Scott Shapiro

Mr. Shapiro of Downey, Brand LLP of Sacramento, offered the following comments in an e-mail on December 15, 2006:

I guess I want to start with the question, "why are we asking?" I am going to presume that we are talking about this because the Reclamation Board has pending and future applications that will make the Reclamation Board grapple with the essential question of how to treat these applications. If that is the case, I think it is important to remember why these applications are before the Reclamation Board at all.

The Reclamation Board is the protector of the federal project. The Corps designed and constructed the project and handed it to the Reclamation Board to protect. As I read the water code, the job of the Reclamation Board is to ensure that any action requiring an encroachment permit will not have a negative impact on the federal project operating the way it was intended.

As I understand it, the criteria developed for the project really relate to stage and flow. The project was presumed to be sound so long as water did not exceed a certain stage at a design flow (the 1957 profile). For this reason, I think that the correct framework for the Reclamation Board to consider hydraulic impacts is to determine whether the changes proposed for the system will raise the stage at the design flow (number 1 below). Frankly, I have never understood how the Reclamation Board could have a basis for any different test. Indeed, unless I am mistaken, any hydraulic impact analysis conducted by the Corps for the system uses the test under #1 below. I do not believe that the Corps, the legislature, or the Courts (Paterno included) intended to make it harder for communities to protect themselves.

I also want to note that I do not understand how the State could adopt a test based on AEP, EAD, or damages generally. Annual exceedence probabilities change regularly. And how do we pick which one to use? Do we say 100? or 200? Why not 10,000? There is no logical basis for selecting any of these because the system was not designed with any of them in mind. Similarly, while I don't have an engineer's understanding of EAD, aren't many of the input factors subjective? If so, that makes the test hard to administer and easily subject to challenge. Similarly, I don't understand how measures of damages are an appropriate standard. Damages were never part of the equation for system design.

I think that some of the tests you identify below, and some of the proposed mitigation, are really issues to be addressed under CEQA. CEQA requires that we determine impacts on others, often using some of the tests below, I think CEQA is the proper place to address these issues.

As we consider this issue, we must remember what the role of the Reclamation Board is and not use this issue to expand that role. If the legislature chooses to endow the Board with greater responsibility, that is legitimate public policy. But these issues should not be used to expand the Board's role without that authority.